NATURAL RESOURCES

WILDFIRE SEASON 2022 WORK OF WILDFIRE ASSESSMENT

Forest Health Science Team
Forest Resilience Division

This report provides a rapid evaluation of the effects of the 2022 wildfires on forest landscape resilience and wildfire risk reduction objectives across Washington State

MARCH 2023

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES

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Wildfire Season 2022 - Work of Wildfire Assessment

EXECUTIVE SUMMARY

The 2022 wildfire season had significant impacts on communities and ecosystems across Washington State. The fires affected air quality and community health, transportation networks, timber resources, recreation and rural livelihoods, and local businesses due to smoke, road closures, and evacuations. The 2022 fires also had substantial effects on forested landscapes and the many benefits they provide to people, particularly in western Washington.

In 2017, the Washington State Department of Natural Resources (DNR) launched the 20-Year Forest Health Strategic Plan: Eastern Washington (20-Year Plan) to accelerate work on landscape-scale wildfire risk reduction, restoration, and climate adaptation across all lands. Over the past five years, DNR staff have collaborated with many partners to prioritize planning areas, determine landscape treatment needs, implement forest health treatments, and develop a monitoring program to track changes in both landscape conditions and treatment effectiveness.

This report presents the second annual assessment of the Work of Wildfire - the degree to which fire effects are consistent with landscape resilience and wildfire risk reduction objectives. Because the 2022 fire season had widespread effects in western Washington, we broadened our assessment to encompass eastern and western Washington, which have distinct historical fire regimes and contemporary fire effects on forest health. While the Work of Wildfire metrics in eastside forests focus on burn severity variation among forest composition types, our metrics in westside forests focus on the amount and pattern of forest structure types. Here, we summarize results covering all of Washington, eastern Washington, and western Washington. We note that nearly all of the wildfires in this report were managed for suppression objectives and that our results are based on preliminary burn severity maps that may change due to delayed tree mortality and other factors.

Statewide summary

Across Washington, fire affected 178,900 acres, including 101,600 forested acres. For both forested and non-forested areas, total fire extent was far less than 2021 (463,345 forested acres) and less than half of the most recent 10-year average. In stark contrast to typical fire seasons, fire affected more forested areas in western Washington (53,600 acres) than in eastern Washington (48,000 acres) (**Figure 1, Table 1**). In addition, western Washington experienced more low-severity fire (48% of total) than eastern Washington (39% of total).

Work of Wildfire in eastern Washington

Fires reduced fuels and fire risk on 12,150 acres that burned at low and moderate severity in dry and moist forests. This estimate is far below the 2021 total (230,000 acres) and the historical annual average (227,650 acres). In dry and moist forests, only 3,150 acres burned at high severity, and there were no large patches of high-severity fire in dry or moist forests, in contrast to 2021. Cold forests accounted for over two-thirds of fire extent, which is atypical compared with most years in the recent past as well as historical fire regimes. The largest fire in eastern Washington, the Parks Fire, burned approximately 19,500 acres of cold forest, including some large high-severity patches.

Work of Wildfire in western Washington

2022 was the largest fire year in recent western Washington history, serving as a wake-up call to prepare for a truly large fire year that will occur in the future when ignitions converge with dry fuels and high wind events. The majority of acres burned during periods of moderate and mild fire weather conditions, resulting in low and moderate severity. Only 27% of the total acres burned at high severity. High-severity fire potentially initiated 14,650 acres of early-seral habitat, contributing to habitat diversity throughout the region. The quality of this habitat, however, will vary depending on the structure of the forest that burned and post-fire management actions. Low- and moderate-severity fire affected 29,650 acres of young and mature forest, likely contributing to higher structural and compositional diversity. The largest fire in western Washington, the Bolt Creek Fire, exhibited major wind-driven "blow-up" days, where large areas burned at high severity.

Management implications

These findings and other recent studies highlight the following management implications: (1) In eastern Washington, relatively mild fire years have more favorable conditions to accomplish positive work through prescribed fire and wildfire management operations. Assessing how to increase the beneficial Work of Wildfire is critical to achieving risk reduction and restoration goals; (2) Throughout western Washington, fire prevention and suppression remain important strategies, particularly during red flag conditions. Landscape-scale fuels treatments are not likely to reduce wind-driven fire behavior in western Washington, although treatments may be warranted near communities, infrastructure, and vulnerable habitats; (3) The re-emergence of large fires in western Washington underscores the importance of emergency preparedness, including evacuation planning for communities, home hardening and defensible space treatments, as well as establishment of potential control lines along key roads and other features.

In addition to these key findings and implications, the 2022 wildfire season demonstrated multiple lessons for ongoing and future work. Given recent trends and climate projections, wildfire will continue to be a significant disturbance agent shaping forest health and landscape resilience. Evaluating the positive and negative effects of wildfires will become increasingly important for adaptive management throughout the western U.S.

INTRODUCTION

Across the western United States, the need for large-scale intentional management to increase landscape resilience to wildfire and climate change has been clearly established (Prichard et al. 2021). In parallel with efforts to increase the pace and scale of forest health treatments, wildland fires and fire management are increasingly recognized as both challenges and potential solutions for landscape restoration and climate adaptation (Dunn et al. 2020, National Cohesive Wildland Fire Strategy, U.S. Forest Service Wildfire Crisis Strategy). Specifically, in addition to the widespread social, economic, and environmental impacts of wildfires, fires often have effects – such as reduced tree densities and surface fuel loadings – that lower risks from, and increase resilience to, future wildfires and drought (Fettig et al. 2019, Cansler et al. 2022, Taylor et al. 2022, Greenler et al. 2023, Laughlin et al. 2023). Wildfires also can enhance wildlife habitat and aquatic systems by increasing snow pack and stream flow (Rieman et al. 2012, Wine et al. 2018, Dickerson-Lange et al. 2021). Managers, scientists, and stakeholders are thus continuing to develop methods to integrate this positive "work" of wildfire into landscape restoration efforts while also mitigating the negative impacts of fires (Dunn et al. 2020, North et al. 2021, Ager et al. 2022, Larson et al. 2022).

In 2017, the Washington State Department of Natural Resources (DNR) launched the 20-Year Forest Health Strategic Plan: Eastern Washington (hereafter "20-Year Plan") to accelerate landscape-scale wildfire risk reduction, restoration, and climate adaptation efforts across all land ownerships. Over the past five years, DNR staff have collaborated with many partners to prioritize planning areas, determine landscape treatment needs, implement forest health treatments, and develop a monitoring program to track changes in landscape conditions as well as treatment effectiveness. This report is the next annual installment following the 2021 Work of Wildfire report (available online), and it complements parallel efforts that have evaluated fire effects and the utility of treatments for multiple objectives (**Appendix A**). Because the 2022 fire season affected western Washington forests and communities, this report also extends and generalizes the Work of Wildfire framework to cover forest health, landscape resilience, and wildfire risk reduction objectives across both eastern and western Washington.

In 2022, fire extent was far less than in 2021, particularly in eastern Washington (**Figures 1 and 2)**, but there were widespread effects on social, economic, and ecological values. Socio-economic impacts were substantial and were in many ways more significant than the ecological impacts. Smoke affected most of Washington during much of September and October, causing health impacts and disrupting livelihoods and outdoor activities for millions of people. Additionally, evacuations and road closures impacted communities throughout the western Cascades. By the end of the dry fall and extended fire season, 178,900 acres burned, including 101,600 acres of forest (**Table 1**). Importantly, the total area burned in 2022 is just one component of wildfire impacts, and the 2022 fire events enable researchers and managers to unpack the range of outcomes across a gradient of fire effects, forest types, and management objectives.

This report presents results of the 2022 DNR Work of Wildfire Rapid Assessment. The goal of this effort was to develop a rapid, data-driven evaluation of the effects of the 2022 wildfires across Washington State. Collaborating with partners within and outside of DNR, the Forest Health Science Team quantified how fires influenced forest composition and structure across all lands with a wide range of management objectives. Because few acres burned within DNR priority planning areas or recent forest health treatments in eastern Washington, we did not focus on updating treatment needs for planning areas, assessing how fires burned in treated areas, or evaluating how treatments were utilized in wildfire management operations, although those are key topics for future fire seasons. This report is intended to provide complementary information to the annual wildfire season report that is prepared by the DNR Wildland Fire Management Division, which focuses on fire operations, economic costs, and damage to structures and resources (available online). Here, we present methods and results covering all of Washington, with subsections for eastern and western Washington.

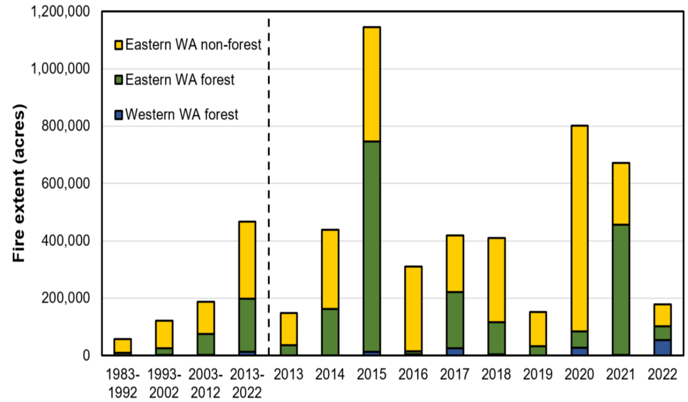

Figure 1. Total fire extent (acres) across Washington State from 1984 to 2022 by decadal average and individual year (2013-2022; bars to the right of the dashed line). Fire perimeters are compiled by the WA DNR Wildland Fire Management Division. 2015, 2020, and 2021 have been the largest fire years to date.

Table 1. 2022 wildfire extent and severity by forest and nonforest vegetation types. Estimates are preliminary and will change due to delayed tree mortality and other factors. Severity is not directly applicable to nonforest. Unknown severity is due to unavailable imagery that will be collected when severity is re-assessed in the fall of 2023.

Vegetation Type	High	Moderate	Low	Unknown	Total
Eastern WA	32,684	25,801	37,402	113	124,494
Dry	2,094	2,379	2,581	1	7,056
Moist	1,080	1,840	5,344	52	8,317
Cold	13,167	8,681	10,776	3	32,628
Forest subtotal	16,342	12,900	18,701	57	48,000
Nonforest	na	na	na	na	76,494
Western WA	29,370	23,525	51,433	2,890	54,298
Moist	4,493	4,641	9,978	184	19,295
Cold	10,192	7,122	15,739	1,261	34,314
Forest subtotal	14,685	11,762	25,717	1,445	53,609
Nonforest	na	na	na	na	689
Forest total	31,027	24,663	44,418	1,501	101,609
Grand total	31,027	24,663	44,418	1,501	178,792

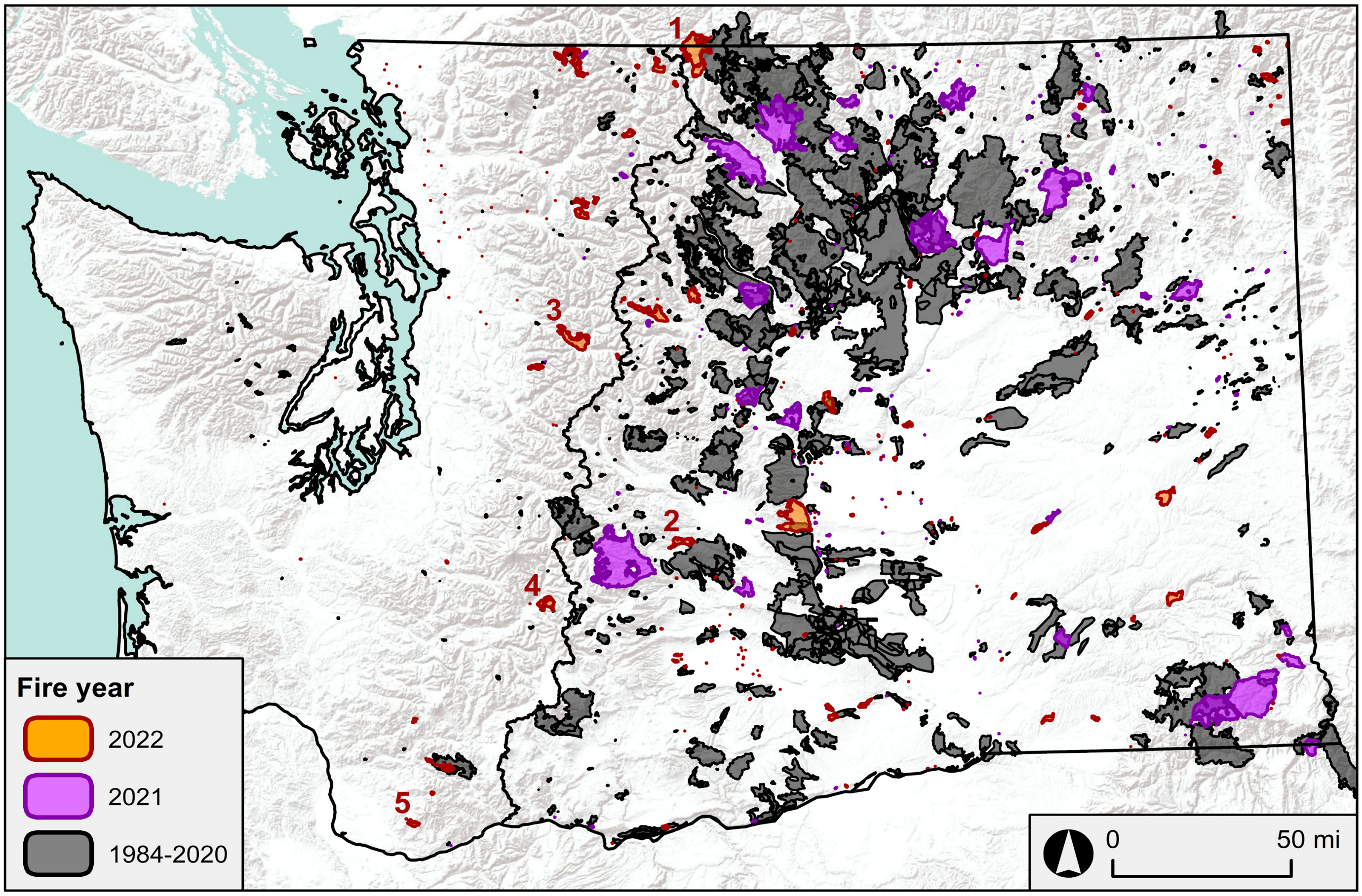

Figure 2. Recent fire patterns across Washington State from 1984 to 2022. Fire perimeters are compiled by the WA DNR Wildfire Division. The vast majority of fire extent has occurred in eastern Washington, delineated by the crest of the Cascade Range (black line). Red numbers indicate individual large fires highlighted in this report (**Figures 4-5, 8-10**): 1: Parks; 2. Cow Canyon; 3. Bolt Creek; 4. Goat Rocks; 5. Nakia Creek. Service layer credits: Esri, USGS, NOAA.

ASSESSING THE WORK OF WILDFIRE IN EASTERN VS. WESTERN WASHINGTON

In the 2021 Work of Wildfire report, we developed a framework based on the 20-Year Plan that lays out the ecological and social basis for landscape-level treatments to reduce wildfire risk reduction and restore resilient, climate-adapted conditions in eastern Washington. Our approach was based on well-established restoration principles, such as reducing surface fuels and tree densities, conservation of large and old trees, and restoring landscape-level structure and patch sizes (Agee and Skinner 2005, Hessburg et al. 2015, Prichard et al. 2021). Underlying our assessment of fire effects was a comparison of the extent and proportion of low-, moderate-, and high-severity fire across forest types to ranges from historical fire regimes that maintained resilience conditions while providing for a wide range of ecological functions (Keane et al. 2009, Hessburg et al. 2019), including less intense and severe wildfires (Fule 2008).

In 2022, a broader framework was necessary to assess the effects of wildfires on forest health and resilience across both eastern and western Washington. We developed new approaches and metrics for western Washington because fire plays a fundamentally different ecological role. Forests in western Washington are generally not dependent on frequent (5-25 years) or semi-frequent (25-100 years) fire to reduce fuel loads, maintain high fire resistance, and sustain low to moderate tree density over time like they are in eastern Washington (Agee 1996). In many western Washington areas, forests developed under a low-frequency (200-400+ years), high-severity fire regime. Westside fires are primarily weather driven and are rarely limited by fuels (Halofsky et al. 2018), particularly when low fuel moistures combine with fire ignitions and strong east winds bringing low humidity (Cramer 1957, Reilly et al. 2022). When these conditions aligned historically, large, high-severity, stand-replacing fire patches occurred, resetting forest development over hundreds of thousands of acres and creating structurally complex, early-seral habitat (Donato et al. 2020, Reilly et al. 2022).

Although infrequent, high-severity fires shape forest landscapes in western Washington, low- and moderate-severity fire effects also play an important role. Since 1984, almost half of the fire extent has been low and moderate severity (Harvey et al. In prep). Historically, lower elevation forests in much of western Washington are thought to have had a mixed-severity fire regime (Spies et al. 2018). Indigenous burning occurred in western Washington to maintain oak woodlands, prairies, camas production, huckleberry areas, and other resources (Boyd 1999, Wray and Anderson 2003). Emerging research indicates that fire was even more frequent than previously hypothesized in the western Cascades (Andrew Merschel, pers. comm.), but

Table 2. Forest health effects of wildfires (bold italic) used to assess the work of wildfire in eastern vs. western Washington. Metrics used to quantify these effects are also shown. See **Appendix B** for full description of methods.

Eastern WA	Western WA
1. Distribution of burn severity relative to historical fire regimes	***1. Distribution of burn severity relative to forest structure stages***
Proportion of low-, moderate-, high-severity fire in different forest types relative to historical ranges, focusing on high severity in dry and moist forests.	Proportion of low-, moderate-, high-severity fire in very young, young, mature, and old forest structural stages.
2. Reduction of surface fuels and tree densities	***2. Diversification of dense, mid-seral forest***
Acres of low- and moderate-severity fire in dry and moist forests.	Acres of low- and moderate-severity fire in dense, young and mature forests..
3. Simplification of landscape pattern from large, high-severity patches	***3. Creation of early-seral habitat***
Acres of medium to large (100+ acres) high-severity patches in dry and moist forests.	Acres of high-severity fire in mature and old-growth forest (structurally complex habitat) and very young and young forest (diverse habitat).
4. Potential forest conversion due to tree seed source limitation	***4. Delayed tree regeneration due to seed source limitation***
Acres of high severity >500 feet from an unburned, low-, or moderate-severity pixel.	Acres of high severity >500 feet from an unburned, low-, or moderate-severity pixel and largest patch index of high-severity fire.
5. Loss of large trees in open- and closed-canopy forests	***5. Loss of old-growth forest***
Acres of large trees burned at high severity.	Acres of old forest burned at high severity, as well as proportion of total.
6. Impacts to riparian and aquatic systems	***6. Impacts to riparian and aquatic systems***
Burn severity in stream-adjacent forests.	Burn severity in stream-adjacent forests.

fire was still less frequent and more variable over time than in most of the eastern Cascades (Agee 2003).

Unlike in eastern Washington, low- and moderate-severity fire effects do not have a lasting effect on reducing future fire intensity by consuming surface fuels, maintaining low tree densities, and favoring fire-adapted tree and understory plant species (Halofsky et al. 2018). This is due to lower frequency of fire, rapid regrowth of fuels, and the fact that most of the burned acres are wind driven. In fact, reburns have occurred after many of the past large fires in western Washington and Oregon, such as the Yacolt, Tillamook, and more recently the Warner Creek Fire in the Oregon Cascades (Gray and Franklin 1997, Evers et al. 2022). Nevertheless, low- and moderate-severity fire can have positive ecological effects, such as creating more variable forest structure and diverse understory plant communities.

Overall, wildfire frequency and severity, as well as vegetation conditions, are not departed from historical conditions in western Washington in the same way that they are in most of eastern Washington (Donato et al. 2020, Hagmann et al. 2021). Thus, comparing burn severity proportions by forest type to historical ranges is not a useful approach for western Washington fires. Due to this fundamental distinction, as well as other differences in forest development, disturbance regimes, and landscape conditions, we developed a parallel set of forest health effects and related metrics to quantify the Work of Wildfire in western Washington for this report (**Table 2**).

While the Work of Wildfire metrics in eastern Washington focus on burn severity variation among forest composition types (dry, moist, cold), our metrics in western Washington focus on the amount and pattern of forest structure types (**Table 2, Appendix B**). Here, we base forest structural stages on tree height using remotely sensed height data and thresholds for different stages: very young (<40 feet), young (40-90 feet), mature (90-140 feet), and old forest (>140 feet). This simple approach works well to characterize structural conditions and age-based developmental stages (King 1966, Franklin et al. 2002), although site productivity, management history, and disturbance history create substantial variability. In addition, we did not separate severity results by forest type because the fire regimes of moist and cold forests in western Washington are similar and because there was minimal 2022 fire acreage in low elevation, drier moist forest that historically burned more frequently (Spies et al. 2018).

Quantifying the effects of wildfires in both eastern and western Washington relies on a standard mapping method for the rapid assessment of burn severity using satellite imagery. We adapted the U.S. Forest Service Region 6 approach to map low-, moderate-, and high-severity fire corresponding to 0-25%, 25-75%, and 75-100% tree basal area mortality. This approach is similar to the RAVG program (https://burnseverity.cr.usgs.gov/ravg/). **Note that our burn severity maps are preliminary and do not capture delayed mortality.** We thus anticipate that severity estimates will increase in subsequent years (Cansler et al. 2020). Given the need for timely adaptive management information, we decided that using initial severity maps was acceptable, although we will continue to evaluate severity patterns using over time. We are currently evaluating initial and extended assessments of the 2021 fire season. Finally, all numbers in the report text have been rounded to the nearest 50 (e.g., 1,215 changes to 1,200) to aid in comparisons and because values may shift slightly due to uncertainties in rapid burn severity assessments. Values in the figures and tables have not been rounded. See **Appendix B** for detailed methods.

Box 1. Definitions (See DNR online glossary)

Burn severity: This report focuses on satellite-based estimates of tree mortality, a common metric of the ecological effects of fire. Low-, moderate-, and high-severity fire classes correspond to 0-25%, 25-75%, and 75-100% tree basal area mortality.

Forest health: The condition of a forest ecosystem reflecting its ability to sustain characteristic structure, function, and processes; resilience to fire, insects and other disturbance mechanisms; adaptability to changing climate and increased drought stress; and capacity to provide ecosystem services to meet landowner objectives and human needs.

Forest health treatment: Treatments that reduce tree density, alter forest structure, and reduce surface and ladder fuels through mechanical (commercial and non-commercial) and fuel reduction (prescribed fire, piling and burning, etc.) techniques to achieve forest health and/or resilience objectives.

Forest structure and age:

EWA large tree: Overstory diameter >20 inches.

WWA very young forest: <40 feet.

WWA young forest: 40-90 feet.

WWA mature forest: 90-140 feet.

WWA old forest: >140 feet.

Fuels: Shrubs, grasses, small trees, litter, duff, and dead wood.

Landscape resilience: The ability of a landscape (or ecosystem) to sustain desired ecological functions, robust native biodiversity, and critical landscape processes over time and under changing conditions. Management activities or natural disturbances increase resilience where they reduce departure of current conditions and desired conditions based on historical and future ranges of variation (HRV, FRV).

Vegetation types:

EWA cold forest: Upper elevation mixed-conifer forests with high-severity fires every 80-200+ years.

EWA dry forest: Ponderosa pine and Douglas-fir dominated forests that historically had surface fires every 5-25 years.

EWA moist forest: Forests that historically had mixed-severity fires every 30-100 years and were composed of fire-resistant (western larch, Douglas-fir) and fire-intolerant (grand fir) trees.

Non-forest: Grasslands and shrublands that may have oak woodlands or ≤10% conifer cover. Also includes agriculture and developed areas.

WWA cold forest: High elevation silver fir and mountain hemlock with very infrequent (400+ year), high-severity fire. Western hemlock and subalpine fir are also common.

WWA moist forest: Low- to mid-elevation western hemlock and Douglas-fir forest with infrequent (200-400 year), high-severity fire. Western redcedar and hardwoods are common.

Work of wildfire: The degree to which fire effects are consistent with science-based landscape resilience and wildfire risk reduction objectives.

2022 SUMMARY ACROSS WASHINGTON

An unusually cool, wet spring followed by an extended fall led to a delayed, yet long-lasting, fire season in 2022. Many communities experienced long-duration smoke impacts, evacuations, and damage to property and other resources, especially in western Washington. Across the state, fire affected 178,900 acres, including 101,600 forested acres (**Figures 1 and 2**). For both forested and non-forested areas, the total fire extent was less than half of the most recent 10-year averages (2013-2022) and similar to the prior decade (2003-2012) (**Figure 1**). In stark contrast to typical fire seasons, fire extent in forested areas was higher in western Washington (53,600 acres) than in eastern Washington (48,000 acres) (**Figure 1, Table 1**). While westside fires were distributed throughout the Cascades, eastside fires were concentrated in the northern portion of the Cascades (**Figure 2**). Remarkably, there were no significant fire events in the Blue Mountains and only five fires >500 acres in northeastern Washington (**Figure 2**).

In terms of forest types and fire effects, fire affected more cold forest than moist forest or dry forest in both eastern and western Washington, and burn severity was relatively evenly mixed among low, moderate, and high severity across forest types (**Table 1**). Low severity was the most common outcome across all forest types except cold forests in eastern Washington. Western Washington experienced relatively more low-severity fire (48% of total) than eastern Washington (39% of total) (**Table 1**). In the following sections, we report detailed fire patterns and forest health effects for eastern and western Washington, including impacts across different land ownerships and for individual large fires.

2022 WORK OF WILDFIRE IN EASTERN WASHINGTON

Overview

There were 45 fires that burned more than 100 acres in eastern Washington during 2022 (**Figure 2**). Wildfire extent totaled approximately 124,500 acres, with 48,000 acres in forested areas (**Table 1**). The vast majority of 2022 forested acres in eastern Washington burned on federal lands (43,400 acres; 91%), with most of the remainder burning on DNR Trustlands (1,950 acres; 4%), industrial (1,350 acres; 3%), or private non-industrial lands (950 acres; 2%) (**Table 3**).

While the number of fires in eastern Washington was similar to the 10-year average (WA DNR Wildfire Report), fire extent was significantly lower due to favorable weather and fuel conditions, in addition to rapid initial responses (**Figure 1**). Specifically, fuel moisture remained high through July, limiting early season fire activity and giving fire managers time and capacity for fire suppression operations. The 2022 fire year was thus a welcome break from the large fire years that have stressed fire operations personnel and communities in eastern Washington over the last decade. Despite relatively low wildfire extent, multiple communities experienced long periods of smoke near large fires, including Wenatchee, Leavenworth, and the Methow Valley (Washington Smoke Information). These long-duration fires were ignited by lightning in remote, rugged locations with limited direct suppression options and persisted due to the lack of any season-ending rain or snow.

Table 3. 2022 eastern Washington wildfire extent and severity by potential vegetation type and ownership*. The vegetation map is based on USDA Forest Service layers compiled by WA DNR. The ownership map is based on 2019 WA county tax parcel data and public ownership data (WADNR 2020). Severity estimates are preliminary and will change due to delayed tree mortality and other factors. The 2022 fires affected economic objectives most directly in high-severity portions of DNR Trustlands, small private, and industrial lands (~1,550 acres). *Burn severity could not be calculated for a small number of acres (125 acres in eastern Washington), which are excluded from the table.

Forest	Burn severity	Federal	Tribal	DNR Trustlands	Other State	Small Private	Private Industrial	Unknown	Total
Dry	High	1,213	0	606	17	206	0	52	2,094
	Low-Mod	2,708	39	1,348	53	717	0	96	4,960
Moist	High	942	0	2	0	1	134	1	1,080
	Low-Mod	6,900	0	13	3	14	253	0	7,184
Cold	High	12,585	0	0	0	0	582	0	13,167
	Low-Mod	19,056	0	4	8	0	390	0	19,457
Total forest	na	43,405	39	1,974	81	938	1,359	149	47,944
Nonforest	na	4,389	1,312	2,978	28,914	6,218	132	32,482	76,425
Total	na	47,794	1,351	4,952	28,995	7,156	1,491	32,631	124,369

Most of the forested area burned in eastern Washington in 2022 was in cold forests, in contrast to previous years where the majority of acres burned in dry forests. More cold forests burned in 2022 (32,650 acres) than historically (23,150 acres), although the cold forest acreage was less than the most recent 10-year average (49,850 acres) (**Figure 3**). Moist forest fire extent (8,300 acres) was much lower than both the 10-year and historical averages (28,350 and 28,550 acres, respectively). Dry forest fire extent (7,050 acres) was also much lower than either the most recent 10-year average (106,000 acres) or historical average (231,950 acres) (**Figure 3**).

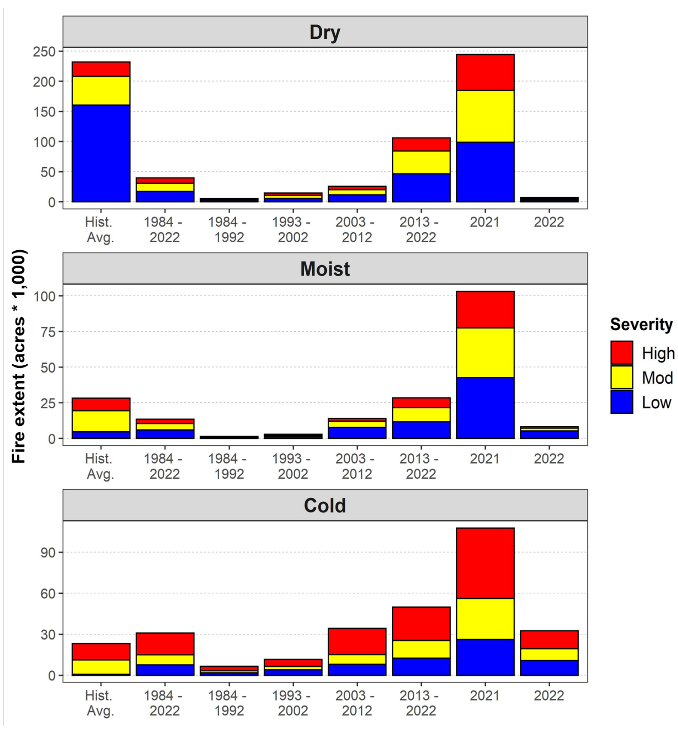

Figure 3. Estimated burn severity* across forested areas of eastern Washington from 1984 to 2022 and historically by potential vegetation type (Haugo et al. 2019). Low-, moderate-, and high-severity classes correspond to 0-25%, 25-75%, and 75-100% tree basal area mortality, respectively. *Burn severity could not be calculated for a small number of acres, which are excluded from the figure. Severity estimates are preliminary and will change due to delayed tree mortality and other factors.

A tradeoff of a low-acre fire year like 2022 is that there were limited beneficial wildfire impacts. Only 12,150 acres of low- and moderate-severity fire, which reduce surface fuels, tree densities, and associated fire risks, occurred in dry and moist forest in 2022, compared with 230,000 acres in 2021. Based on historical fire regimes, dry and moist forests in eastern Washington need an estimated average of 227,650 acres of low- and moderate- severity every year to maintain low fuel loads and lower fire intensity, although this fluctuated considerably from year to year (Haugo et al. 2019, Donato et al. In prep). From 1986 to 2017, wildfires were the primary disturbance agent reducing restoration need in eastern Washington, but this reduction was offset by vegetation growth that increased need every year (Laughlin et al. 2023).

In addition to the low wildfire extent, preliminary numbers suggest that relatively little prescribed fire was conducted in 2022 (WA DNR 2022). This lack of prescribed fire was due in part to a national pause on burning U.S. Forest Service land from May until September as well as limited resource availability in the fall due to extended suppression activity and conflicting resource priorities. The 2022 burn season provided relatively short and limited weather windows in which land managers could achieve their fuels management objectives between periods of high moisture closely followed by drying periods with increased fire behavior. In previous years, surface fuel treatments have also been relatively limited. From 2017 to 2021, an annual average of 23,800 acres of prescribed fire and piling and burning treatments were completed (WA DNR 2022), although ongoing DNR efforts are prioritizing prescribed fire planning and implementation.

Finally, although the influence of forest health treatments on fire outcomes was a focus of the 2021 Work of Wildfire report, further analysis of treatment-fire interactions was not possible in 2022 because very few treated acres burned. The Cow Canyon Fire was the only fire to partially overlap previous treatments, and those treatments were limited to very small areas of hand cutting and non-commercial thinning from a single year. We are actively working with partners to assess treatment effects on fire behavior, severity, and operations in more detail.

Table 4. 2022 eastern Washington total acres, forested acres, and acres burned by forest type and burn severity for the 10 large fires that burned >1,000 acres total (and >100 acres of forest), plus all other fires combined and regional totals. Bold italic numbers indicate values above the historical reference range for that forest type-severity combination. Historical severity proportions are from Landfire as applied by Haugo et al. (2019). *The Parks Fire includes the Kid Fire and extended across the U.S. border into Canada. Only the portion of the fire in Washington was assessed for this report. The White River Fire includes the Irving Peak Fire.

Fire Name	Total Extent	Forested Extent	Dry Forest		Moist Forest		Cold Forest	
			High	Low-Mod	High	Low-Mod	High	Low-Mod
Parks*	22,463	20,649	***640***	557	1	0	10,265	***9,185***
White River	11,115	10,608	36	502	230	***2,302***	1,130	***6,408***
Cow Canyon	5,810	2,313	***797***	1,502	3	10	0	0
Minnow Ridge	5,132	4,961	88	1,072	78	1,102	506	***2,114***
Boulder Mountain	2,235	2,103	2	<1	244	565	809	***482***
Thor	2,020	2,019	2	152	76	***884***	246	***657***
Williams Lake	1,870	177	8	***169***	0	0	0	0
Slate Creek	1,323	1,323	3	160	13	***1,084***	1	***62***
Seven Bays	1,233	402	14	388	0	0	0	0
Diamond Watch	1,209	1,196	16	183	74	***914***	0	***10***
All other fires	69,959	2,196	489	276	362	322	209	538
Total	124,369	47,947	2,094	4,960	1,080	7,184	13,167	19,457

Effects of wildfires on forest health and resilience (eastern Washington)

The 2022 wildfires in eastern Washington had mixed impacts in terms of landscape resilience and wildfire risk reduction goals, depending on forest type, fire extent, and severity (**Figure 3**). Below, we describe the overall impacts of the fires for each of the forest health effects listed in **Table 2**. We also include results from individual fires to provide more detail on specific effects. Due to the lack of very large fires compared with 2021, we did not include a section on individual fires, although we present results for the 10 largest fires (>1000 acres) in **Tables 4 and 5**. Note that fire effects for the majority of fires and burned acres occurred under suppression objectives. Notably, fire teams on the Parks Fire utilized the lightning ignition for resource benefit, to maximize firefighter safety, and reduce fire costs due to the wilderness location and extremely difficult terrain. Also, although the Parks Fire extended into Canada, only the portion of the fire in Washington State was considered for these analyses. See **Appendix B** for a detailed description of the methods used to generate these results and the rationale behind them.

1. Distribution of burn severity relative to historical fire regimes

Historical fire regimes maintained landscape conditions that were resilient to a range of disturbances and climatic fluctuations (Keane et al. 2009, Hessburg et al. 2019). These historical estimates thus represent reference ranges that are likely to maintain landscapes that provide desired ecosystem functions over time, including lower fuel loads and wildfires that are less challenging to manage (Fule 2008). In dry and moist forests of eastern Washington, frequent (5-25 years) and semi-frequent (25-100 years) fires - ignited by lightning and Indigenous stewardship - were generally low to mixed severity (Agee 1996). Because stand-replacing fire was less characteristic in these forests, the proportion of contemporary high-severity fire in dry and moist forest is especially concerning because large areas of high-severity fire can set back landscape resilience and wildfire risk reduction objectives (Churchill et al. 2022).

While only 7,050 acres of dry forest burned across eastern Washington in 2022, the areas that did burn experienced uncharacteristically severe impacts relative to historical estimates. Burn severity was nearly evenly split among low-, moderate-, and high-severity fire in dry forests (36%, 34%, 30%, respectively; **Table 1**), whereas historically most wildfire in these forests was low severity (69% on average) (**Figure 3**). The majority of dry forest burned in the Parks Fire (includes the Kid Fire) and Cow Canyon Fire (**Table 4**). Both fires had an uncharacteristically high proportion of high severity in dry forests (**Figures 4 and 5**).

Cold forests had less severe wildfire than historical estimates; 33% of cold forests burned at low severity in 2022 compared to an annual average of 3% historically (**Figure 3**). Conversely, 40% burned at high severity vs. an annual average of 52% historically. Moist forests also burned at lower severity (64% low, 22% moderate, 13% high) relative to historical averages (17% low, 52% moderate, and 31% high).

The Parks Fire, White River Fire (includes the Irving Peak Fire), and Minnow Ridge Fire accounted for the majority of burned acres in cold and moist forests (**Table 4**). The Parks Fire mostly followed the historical distribution of burn severity in cold forests, with more low-severity fire than expected (**Figure 4, Table 4**), while both the White River and Minnow Ridge Fires had much more low-severity fire than their historical reference ranges (White River: 56% observed vs. 2-5% historical; Minnow Ridge: 20% observed vs. 1-3% historical).

2. Reduction of surface fuels and tree densities

There is general agreement that fire effects from low- and moderate-severity fires in dry and moist forests are positive (North et al. 2021, Larson et al. 2022, Greenler et al. 2023). Low-severity fire consumes surface fuels and ladder fuels (i.e.,

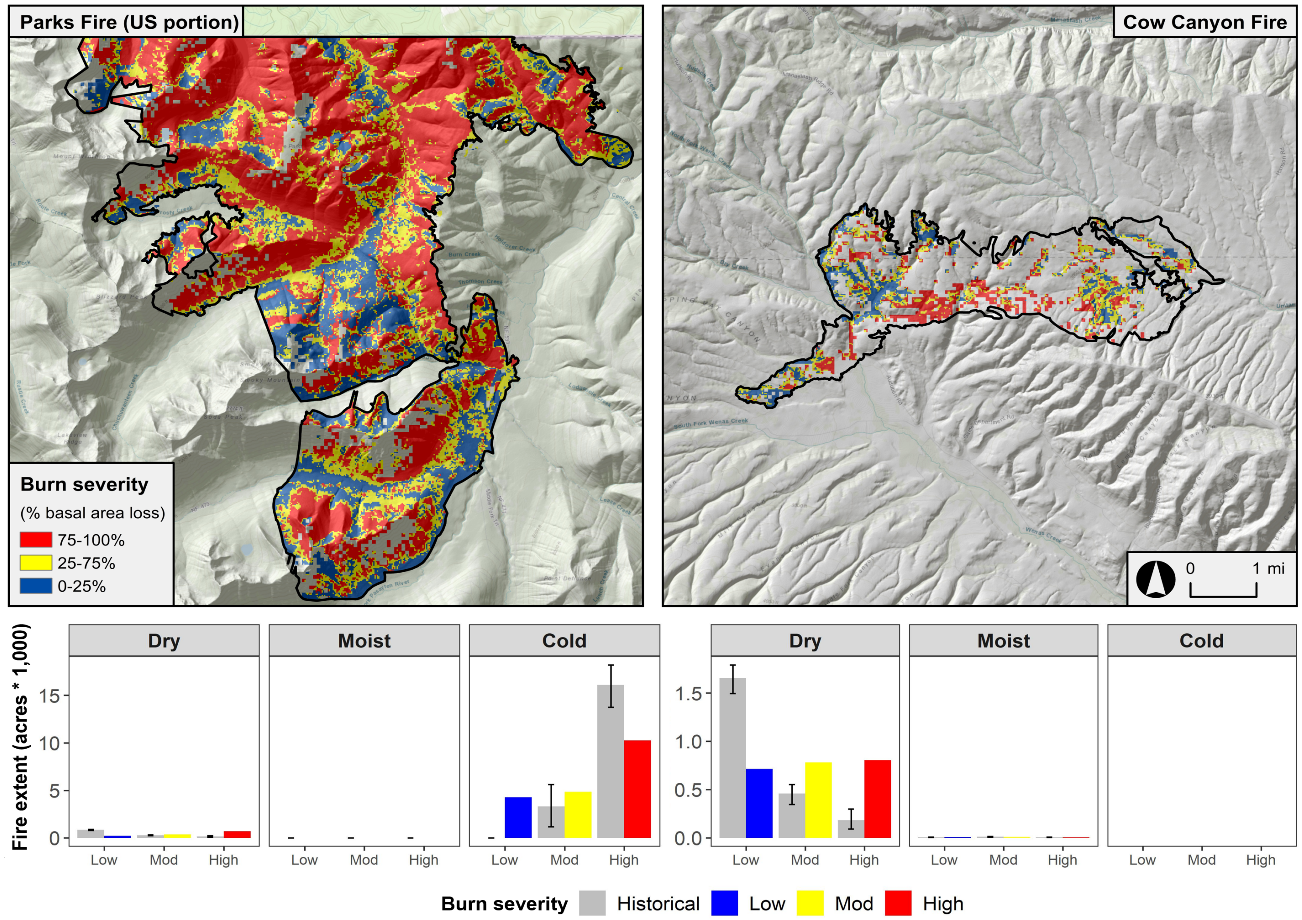

Figure 4. Burn severity of forested portions of the Parks Fire (left) and Cow Canyon Fire (right) in eastern Washington, compared with estimated historical reference ranges (lower panels; Haugo et al. 2019). Fires in nonforested areas are not shown. Only the portion of the Parks Fire in Washington was assessed for this report. Severity estimates are preliminary and will change due to delayed tree mortality and other factors.

small trees, tall shrubs, and lower branches of larger trees), thereby accomplishing some wildfire risk reduction goals for 10-20 years (Cansler et al. 2022). Low- and moderate-severity fires also reduce canopy bulk density (overstory tree densities) and can shift species composition towards fire- and drought-tolerant species, thereby increasing drought resistance. Moreover, moderate severity and multiple fires may be necessary to restore dry forests (Greenler et al. 2023). However, while fire effects are often similar to thinning treatments, moderate-severity fire also generates high levels of dead fuels 5-15 years post-fire that can increase the risk of high-severity fire (Larson et al. 2022).

In 2022, low- and moderate-severity wildfires burned approximately 12,150 acres in dry and moist forests of eastern Washington (**Table 1**), likely leading to forest health improvements. This adds to the reported 309,556 cumulative footprint acres treated over the past six years (2017 to 2022) by mechanical and prescribed fire treatments (WA DNR 2022) Because of the relatively low fire extent in 2022, very little area burned within the 20-Year Plan priority planning areas. These priority landscapes are areas where treatments and beneficial fire effects are especially needed due to high wildfire and drought risk, community exposure if wildfires occur, sensitive wildlife habitat, and other forest health factors.

3. Simplification of landscape pattern from large, high-severity patches of fire

Large, high-severity patches can reduce large tree structure, hinder tree regeneration, and set landscapes up for a cycle of repeating high-severity fire and climate-driven transformation to landscapes

Figure 5. Landscape view of the Cow Canyon Fire showing mostly high-severity fire in open canopy conditions in eastern Washington (photo credit: Danielle Munzing).

Table 5. 2022 eastern Washington work of wildfire metrics (in acres) for individual fires, all other fires, and regional totals: acres of dry-moist forests in large (>1,000 acres), medium (100-1,000 acres), and small (<100 acres) high-severity patches; potential seed source limitation (acres >500 feet from residual live trees); burn severity in areas with large trees, and burn severity in riparian forests. Note that the acres of large tree and riparian forests may overlap, as riparian areas often contain large trees. Large trees were mapped using LiDAR and other data sources with a height cutoff of 100 feet. Riparian forests were mapped using the DNR stream layer with 150 foot buffers for fish bearing streams, 75 foot buffers for non-fish bearing streams, and 50 foot buffers for intermittent streams. See **Appendix B** for full description of methods. *The Parks Fire extended across the U.S. border into Canada; only the portion of the fire in Washington was assessed for this report.

Fire Name	Forested	High-Severity Patches in Dry-Moist Forest			Potential Seed	Large Tree Severity			Riparian Forest Severity		
	extent	Large	Medium	Small	Source Limitation	High	Mod	Low	High	Mod	Low
Parks*	20,649	241	325	72	7,099	1952	857	468	459	463	396
White River	10,608	0	50	213	461	383	1140	3011	84	186	542
Cow Canyon	2,313	0	177	608	376	11	23	54	141	192	201
Minnow Ridge	4,961	0	5	161	159	97	628	1504	98	298	653
Boulder Mountain	2,103	0	204	41	649	29	102	100	19	38	43
Thor	2,019	0	2	75	124	10	38	151	10	18	99
Williams Lake	177	0	0	6	2	0	0	0	1	13	7
Slate Creek	1,323	0	0	16	0	1	8	137	0	3	87
Seven Bays	402	0	0	142	70	0	1	1	74	46	18
Diamond Watch	1,196	0	0	89	14	1	7	13	8	38	101
All other fires	2,196	0	693	40	728	2	29	169	97	6	51
Total	47,947	241	1,456	1,463	9,682	2,486	2,833	5,607	991	1,302	2,199

dominated by young forest, grassland, and shrubland (Cassell et al. 2019, Kemp et al. 2019, Meigs et al. 2022). These patches were historically rare in dry and moist forests (Hagmann et al. 2021). In contrast, small to medium patches of high-severity fire were common historically in dry and especially moist forests. These can play an important role in restoring and maintaining a mosaic of forest age classes, grasslands, and shrublands (Hessburg et al. 2019).

The large patches of high-severity fire in dry and moist forests that were common in the 2021 fires were notably absent in 2022. Although the largest area of high-severity fire in dry forest occurred in the Cow Canyon Fire (**Table 4**), with a higher proportion of high-severity fire than historical reference ranges, the patch sizes were relatively small (**Table 5**). Most of the high-severity fire was in small (<100 acres) patches, and only ~200 acres were in medium patches (100-1000 acres), patterns that were associated in part with the large amount of non-forest vegetation affected by the Cow Canyon Fire (**Figures 4 and 5**)

The vast majority of high-severity fire in cold forest occurred in the Parks Fire (**Table 4**), including many large high-severity patches (**Figure 4**). In contrast to dry and moist forests, large patches were thought to be more common historically in cold forests. However, the large extent and patch sizes of high-severity fire in all forest types in north-central Washington over the last 30 years is exceeding historical fire regimes (Haugo et al. 2019, Donato et al. In prep), increasing the potential for conversion to young forest and non-forest vegetation types outside of historical reference conditions (WA DNR 2021).

4. Potential forest conversion due to tree seed source limitation

Across the interior Western US, lack of tree regeneration and type conversion due to the combination of climatic warming and the increasing extent of high-severity fire is a critical concern (Davis et al. 2023). DNR scientists recently completed an analysis of this risk for the eastern Cascades of Washington (Meigs et al. 2022).

Overall, 9,700 acres that burned in 2022 in eastern Washington may experience tree seed source limitation (**Table 5**). However, only two of the largest ten fires (Parks and Boulder Mountain) had more than 500 acres beyond 500 feet from residual live trees. In the Cow Canyon Fire, which had the highest dry forest acreage of the eastern Washington wildfires, an estimated 16% of the forested acres (400 acres) may experience delayed tree regeneration due to the lack of seed sources. This area is on DNR ownership, however, and much of it was salvage-harvested in the winter of 2022-2023 and will be replanted.

Almost all of the area with potential seed source limitation is within the Parks Fire. An estimated 34% of the forested landscape (7,100 acres) is in high-severity patches more than 500 feet from residual live trees. Most of the Parks Fire occurred in subalpine fir / lodgepole pine forests. Lodgepole pine may regenerate from serotinous cones, which require fire to open. However, other species may take longer to regenerate. As such, it is likely that areas burned at high severity will fill in and be dominated by lodgepole pine for a number of years (Povak et al. 2020). Some areas may remain shrublands or grasslands, which can be beneficial depending on the extent and patch sizes of these areas (Hessburg et al. 2019). However, the large extent and patch sizes of high-severity fire in north-central Washington over the last 30 years may be simplifying landscapes (see #3 above).

5. Loss of large trees in open- and closed-canopy forests

Mortality of large trees from wildfires can be a major setback to wildfire risk reduction and resilience objectives, as they take multiple decades to centuries to grow and serve as a fire-resistant backbone of resilient landscapes (Hessburg et al. 2015). We mapped large trees using a combination of remotely sensed datasets (**Appendix B**).

An estimated 2,500 acres with large trees burned at high severity in the 2022 fires, which is 23% of the total burned area containing large trees (**Table 5**). Across most fires, areas with large trees burned at low severity. In the Parks Fire, however, ~60% of forest with large trees (1,950 acres) burned at high severity (**Table 5**). This result provides further indication that the Parks Fire simplified the landscape and will have long-lasting impacts on fire risk and wildlife habitat.

6. Impacts to riparian and aquatic systems

Wildfires can have large impacts on water quantity, quality, and temperature; sediment budgets and flow; large wood inputs; productivity; and fish habitat quality (Luce et al. 2012, Flitcroft et al. 2016, Wine et al. 2018). While some short-term impacts can be negative, most long-term effects are positive. However, the cumulative effects of multiple, high-severity fires in a warming climate are unknown (Jager et al. 2021).

Burn severity in stream-adjacent forests was 50% low, 30% moderate, and 20% high (**Table 5**). This pattern was present across most large fires. Both the White River and Minnow Ridge Fires had a relatively high proportion of low-severity fire, while the Parks and Cow Canyon Fires had more high-severity fire (**Table 5**). These estimates provide a starting place to gauge the impacts, both positive and negative, of fires on riparian and aquatic systems, including wood and soil deposition to streams, water quantity and quality, and changes to fish and wildlife habitats and populations.

2022 WORK OF WILDFIRE IN WESTERN WASHINGTON

Overview

The 2022 fire season in western Washington was the largest since contemporary record keeping began in 1984. Fifty individual fires burned 54,300 acres, which is approximately double what burned during western Washington's other two recent large fire years (2017 and 2020) (**Figure 6**). Fires occurred along the full length of the western Cascades (**Figure 2**), with significant fires in North Cascades National Park and most of the major river valleys: Skagit, Sauk, Skykomish, Cowlitz, Kalama, Lewis, and Washougal. The majority of burned acres were on U.S. Forest Service (62%) and National Park (24%) ownerships, with 10% on industrial forest land, 3% on DNR Trustlands, and the remaining 1% on other ownerships (**Table 6**). Only 172 acres of small-private forestland burned. An estimated 3,150 acres of private industrial forestland and DNR Trustlands burned at high severity, resulting in significant financial losses and the likely need to replant to meet management objectives (**Table 6**).

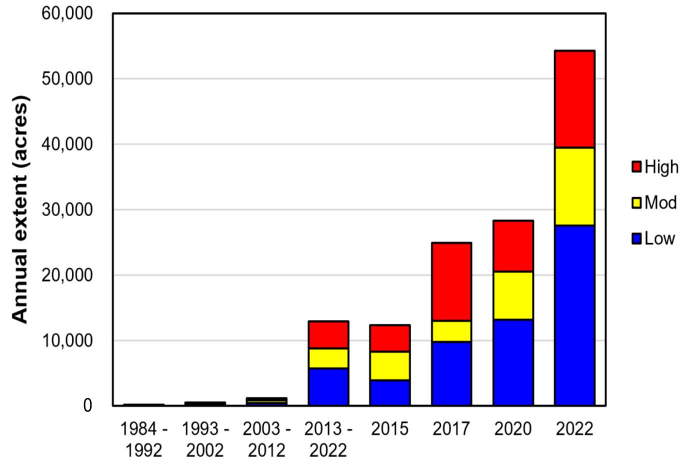

Figure 6. Western Washington fire extent and severity from 1984 to 2022. 10-year increments show annual average during that span. The four individual years (2015, 2017, 2020, and 2022) are the largest four years in this period. Severity estimates are preliminary and will change due to delayed tree mortality and other factors. Fire perimeters are compiled by the DNR Wildland Fire Management Division.

Thirteen fires over 1,000 acres in size made up 91% of the burned acres (**Table 7**). This was in contrast to 2017 and 2020, when far fewer fires burned and one large fire burned almost all of the westside acres (2017 Norse Peak Fire, 2020 Big Hollow Fire). Despite the exceptionally dry fall, only a few big spread days occurred during east wind events, which created large, high-severity patches in two fires (Bolt Creek, Nakia Creek - details below) (**Table 7**). Most acres burned during more moderate fire weather at low (48%) and moderate severity (22%), with only 27% burning at high severity. While 2022 was a big year, and the amount of fire in western Washington has increased in recent decades, it is important to note that only a small fraction of forested acres have burned during this time period (**Figure 6**), and only a third of those acres have burned at high severity.

Table 6. 2022 western Washington wildfire extent and severity by ownership. Severity estimates are preliminary and will change due to delayed tree mortality and other factors. Unknown severity is due to unavailable imagery that will be collected when severity is re-assessed in the fall of 2023.

Burn severity	U.S. Forest Service	National Park	Private Industrial	DNR Trustlands	City-County	Small Private	Other	Total
High	8,119	3,148	2,561	570	254	33	1	14,685
Moderate	7,375	2,784	1,215	116	214	58	0	11,762
Low	17,856	5,552	1,091	850	297	71	0	25,717
Unknown	133	1,198	111	0	3	0	0	1,445
Nonforest	396	54	204	17	3	11	3	689
Total	33,879	12,736	5,182	1,554	770	172	4	54,298

Table 7. 2022 western Washington in 2022 total forested acres; proportion of low-, moderate-, and high-severity; and largest patch index of high-severity fire for individual large fires (>1,000 acres) and across all fires. Largest patch index is the percentage of the total fire extent of the largest, high-severity (HS) patch. Severity estimates are preliminary and will change due to delayed tree mortality and other factors.

Fire Name	Forested extent (acres)	Severity (acres)				Severity (%)				Largest Patch Index (HS)
		High	Mod	Low	Unknown	High	Mod	Low	Unknown	
Bolt Creek	14,451	5,856	3,267	5,315	14	41%	23%	37%	0%	28%
Goat Rocks	6,130	725	1,316	4,039	50	12%	21%	66%	1%	3%
Suiattle River	4,228	551	955	2,722	0	13%	23%	64%	0%	7%
Brush Creek 2	3,355	604	496	1,384	872	18%	15%	41%	26%	8%
Copper Lake	3,160	921	618	1,579	42	29%	20%	50%	1%	19%
Three Fools	3,001	617	859	1,525	0	21%	29%	51%	0%	9%
Silesia	2,426	702	690	1,013	22	29%	28%	42%	1%	10%
Boulder Lake	2,291	529	498	1,228	36	23%	22%	54%	2%	7%
McAllister Creek	2,291	612	705	820	154	27%	31%	36%	7%	13%
Siouxon	2,079	511	417	1,149	1	25%	20%	55%	0%	7%
Nakia Creek	1,891	1,038	357	496	0	55%	19%	26%	0%	54%
Loch Katrine	1,914	643	351	920	0	34%	18%	48%	0%	21%
Little Chill	1,817	578	484	645	110	32%	27%	36%	6%	16%
All other fires	4,576	798	750	2,883	145	17%	16%	63%	3%	na
Total	53,609	14,685	11,762	25,717	1,445	27%	22%	48%	3%	na

In many ways, the 2022 fire year is a precursor of future large fire years and a reminder of historical fire events in western Washington. Compared with the 2020 Labor Day fires in western Oregon that burned over 800,000 acres (Reilly et al. 2022, Evers et al. 2022), 2022 was a relatively small year in terms of both acres and severity. The 1902 Yacolt Fire in southwestern Washington that burned 240,000 acres is another example, as are other historical fires (Donato et al. 2020). If east wind events had been more sustained or intense, 2022 could have been a much bigger year, as fires were burning in September and October throughout the western Cascades. Thus, 2022 is a wake-up call to prepare for a truly large fire year that will occur at some point in the future (Halofsky et al. 2018, Reilly et al. 2022), even though the probability of this occurring is very low in any single year.

The social and economic effects of the 2022 westside fires were substantial and widespread. Smoke impacted most of western Washington during much of September and October, causing health impacts and disrupting livelihoods and outdoor activities for millions of people in western Washington. Air quality was especially bad and long-lasting in Darrington, Index, Skykomish, Packwood, and other communities near the fires. Air Quality Index levels over 200 persisted in these areas for much of September and October. A number of these communities were also evacuated (level 3 evacuations), and many more were on level 2 evacuation notices. Fortunately, no major infrastructure or homes were lost.

Despite the relatively limited extent and low severity of the fires, several of the larger fires were near or adjacent to important travel routes and infrastructure. State Highways 2, 530, 410, and 12 were closed or had restricted access in September, causing substantial impacts to local communities, as well as commercial and non-commercial transportation across Washington. Primary transmission lines along Highway 2 were threatened and were powered down for several days during the worst fire weather. Impacts to soils, slope stability, and landslide potential are significant ongoing concerns due to high-severity fire on steep slopes near highways, transmission lines, and communities. Smoke, highway closures, and closures on parts of national forests and other public lands had a large impact on recreation, tourism, and other businesses along major roads.

Effects of wildfires on forest health and resilience (western Washington)

The 2022 fires in western Washington had a range of positive and negative effects on forest health, some of which depend on landowner objectives and landscape context. Here, we report on the metrics that quantify these effects (**Table 2**) and discuss their ecological significance. A detailed description of the methods used to evaluate these effects is provided in **Appendix B**.

1. Distribution of burn severity relative to forest structure stages

Within the footprint of all the 2022 fires, the most predominant forest structural stages were mature (25,350 acres) and young (15,650 acres) forest, followed by old (5,800 acres) and very young (5,150 acres) (**Figure 7**). Post-fire, high-severity acres of young, mature, and old forest have shifted to the very young class, which rebalanced the distribution of structural stages within the 2022 fire footprints (**Figure 7**). Very young changed from 10% to 33% of the burned footprint, while mid-seral stages (mature and young) changed from 79% to 57%. Old forest decreased slightly from 11% to 10%. Much of this newly created, very young forest stage will develop into structurally complex, early-seral habitat, which has diverse plant communities and abundant dead wood (details below).

The shift in the distribution of structure stages is consistent with overall landscape restoration needs in western Washington

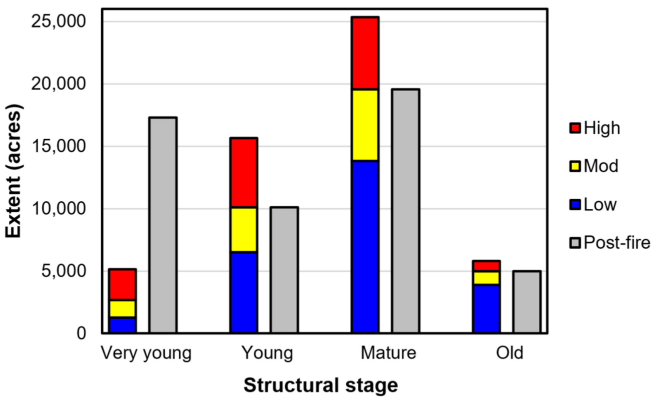

Figure 7. 2022 western Washington wildfire distribution of estimated pre-fire and post-fire structural stages. Remotely sensed, overstory tree height was used to classify the following four stages: very young: <40 feet; young: 40-90 feet; mature: 90-140 feet; and old growth >140 feet. Stacked bars display low-, moderate-, and high-severity extent for each structural stage. Solid gray bars show the estimated post-fire distribution of structural stages based on shifting all acres that burned at high severity to the very young stage. See **Appendix B** for a full description of methods. Severity estimates are preliminary and will change due to delayed tree mortality and other factors.

(DeMeo et al. 2018), given the high abundance of mid-seral stages in western Washington and relative scarcity of early-seral habitat that is not intensively managed for rapid tree establishment (Donato et al. 2020). Furthermore, low- and moderate-severity fire may accelerate the development of old-growth forest characteristics in some of the mid-seral forest. It is important to keep in mind, however, that landscape-level changes in the distribution of structural stages caused by specific fires depend on the size and effects of the fire relative to the condition of the larger landscape that the fire burned in. For example, a small fire in a landscape dominated by very young forest will have minimal effects, while a large fire that burns mostly at moderate to high severity through young, mature, and old-growth forest will have a much greater effect.

In general, burn severity was lower in older structure classes with larger, taller trees; the overall proportion of high severity in very young stands was 48%, compared with 23% in mature forest and 14% in old growth (**Figure 7**). These results highlight that larger trees and older forests are more fire resistant (Zald and Dunn 2018), particularly in topographically protected fire refugia (Meigs et al. 2020), but these effects are diminished during blow-up days (Reilly et al. 2022), as was observed in the Bolt Creek Fire (details below).

2. Diversification of dense, mid-seral forest

The 2022 wildfires will likely lead to more diverse plant communities and complex forest structure in a significant portion of the 19,550 acres of mature and 10,100 acres of young forest that burned at low and moderate severity (**Table 8**). By killing trees and opening the canopy, these fires can accelerate the growth of large trees and understory tree layers, stimulate the diversification and abundance of understory plant communities, generate snags and downed wood, and create gaps and spatial variability (Franklin et al. 2002). These positive effects are most pronounced in dense, young forests that have little understory development and other elements of old forest structure.

In forests that already have substantial canopy layering, downed wood, or a well developed understory plant community, however, less than stand-replacing fire can set back structural complexity and habitat value. In addition, low-severity fire may kill understory tree and shrub layers but not kill enough overstory trees to significantly diversify conditions by altering the understory light environment and creating dead wood, although secondary mortality and blowdown (**Figure 8**) will continue to diversify structure over time in some areas. The degree to which

Figure 8. Bolt Creek Fire patterns and effects. Top panel: High-severity slopes above the community of Grotto. Middle panel: Mixed-severity mosaic near Eagle Creek. Lower panel: Low-severity effects on heavy understory and surface fuels. Photos: Derek Churchill, Garrett Meigs.

Table 8. 2022 western Washington work of wildfire metrics (in acres) for individual large fires (>1000 acres), all other fires, and regional totals. Metrics include: potential seed source limitation (acres >500 feet from residual live trees); creation of early-seral habitat following high-severity fire (structurally complex in old and mature forest, structurally simple in young and very young forest); loss of old forest (high severity acres and percent of total old forest); diversification of mid-seral forest (acres of mature and young forest burned at low and moderate severity); and riparian forest burn severity (same metric as eastern Washington; Table 5). See **Appendix B** for full description of methods.

Fire Name	Potential Seed Source Limitation	Early-Seral Creation		Old Forest Loss		Mid-Seral Diversification		Riparian Forest Severity		
		Complex	Simple	High Severity	% of Total	Mature	Young	High	Mod	Low
Bolt Creek	1,960	2,182	3,688	288	22%	4,395	2,403	973	512	903
Goat Rocks	25	544	166	32	5%	3,593	1,036	6	28	271
Suiattle River	132	337	221	119	8%	1,685	577	75	160	477
Brush Creek 2	3	233	345	35	8%	726	451	14	24	112
Copper Lake	131	581	339	58	13%	1,168	498	57	26	55
Three Fools	37	183	431	1	5%	1,287	850	15	44	165
Silesia	3	471	214	49	11%	898	285	40	55	64
Boulder Lake	122	447	89	123	29%	1,051	333	51	55	138
McAllister Creek	9	170	441	11	12%	594	572	42	64	50
Siouxon	72	315	191	30	32%	933	547	78	83	201
Nakia Creek	356	308	721	1	25%	491	248	172	57	65
Loch Katrine	49	130	513	6	14%	335	649	101	53	160
Little Chill	21	335	240	25	19%	608	237	28	45	56
All other fires	44	350	458	26	12%	1,806	1,411	34	53	294
Total	2,965	6,586	8,057	804	14%	19,570	10,097	1,686	1,259	3,011

westside fires accelerate vs. set back structural development will take time to fully evaluate and is the topic of current research.

Although we cannot precisely estimate how many acres of mid-seral forest (young and mature) benefited from the 2022 fires in terms of diversification, the total is likely significantly higher than current rates of variable density thinning (VDT) treatments in western Washington. VDT was originally based on how moderate-severity disturbances enhance the development of older forest structure in mid-seral forests (Bailey and Tappeiner 1998, Carey 2003). Other the last five years, the Gifford Pinchot, Olympic, and Mt. Baker-Snoqualmie National Forests have collectively conducted an annual average of 2,100 acres of variable density thinning, while DNR has thinned an annual average of 4,700 acres in western Washington.

3. Creation of early-seral habitat

Overall, high-severity fire affected 14,650 acres across western Washington in 2022, setting the stage for the development of early-seral habitat. Habitat quality will depend on pre-fire structure, site productivity, post-fire management, and other factors. High-severity fire in mature and old forest may lead to 6,600 acres of structurally complex, early-seral habitat containing abundant standing and downed dead wood, as well as high plant and animal diversity (**Table 8**). This habitat type supports many species not found in young, mature, or old-growth forests (Swanson et al. 2011, 2014), and is on par with old growth for overall diversity (Smith et al. 2020). Early-seral habitat is very rare in western Washington and Oregon and considered low relative to historical levels and habitat needs for a range of wildlife species (Spies et al. 2019, Donato et al. 2020). High-severity fire in young and very young forest may result in an estimated 8,050 acres of structurally simple, early-seral habitat. These areas may develop high plant diversity but without the large deadwood and live trees associated with structurally complex, early-seral habitat that originates from old-growth or mature forest.

Collectively, the 14,650 acres of early-seral habitat is a substantial addition in terms of landscape diversity, especially as it is well distributed across the Cascades. This adds to the 12,600 acres created by the 2017 Norse Peak Fire and the 7,700 acres in the 2020 Big Hollow Fire (Harvey et al. In prep). This habitat is relatively short-lived, however, as trees naturally regenerate and dominate the site within 20-40 years after a fire (Franklin et al. 2002), although this can take longer in some cases. Salvage of dead trees, as well as rapid reforestation and treatments to control competing vegetation, will reduce early-seral habitat quality and longevity. Where it aligns with landowner objectives, allowing early-seral habitat to develop and persist for as long as possible is generally a positive outcome of wildfires in western Washington. No salvage operations are currently planned on U.S. Forest Service land (except for limited roadside hazard tree removal), while salvaging and/or replanting of young forest is likely on industrial forestland and DNR Trustlands.

4. Delayed tree regeneration due to seed source limitation

An estimated 2,950 acres of the 2022 fires may experience limited or delayed tree regeneration in large, high-severity patches due to seed source limitation (**Table 8**). However, tree regeneration is typically abundant in western Washington forest types, even in large, high-severity patches (Larson and Franklin 2005, Laughlin et al. In prep). Thus, tree regeneration may be sufficient in many locations or possibly delayed for several decades in others, depending on pre-fire conditions, landscape configuration of live and dead trees, and site productivity. Reburns can lead to much longer-term limitations in tree regeneration (Gray and Franklin 1997, Busby et al. 2020).

The implications of delayed tree regeneration depend on landowner objectives and the size of these areas. For landowners with economic objectives or who wish to maximize carbon storage, delayed regeneration can substantially reduce carbon sequestration, biomass accumulation, and future financial returns. This post-fire condition also provides an opportunity for transitions to more climate-adapted plant species (Halofsky et al. 2018). In terms of biodiversity and wildlife habitat, delayed tree regeneration in these areas is generally beneficial due to the rarity and short duration of structurally complex, early-seral communities (See #3 above). Delayed regeneration can also allow seedlings to germinate and establish over a span of years with different spring and summer climate conditions. This climatic variation can enhance genetic diversity and resilience to climate change (Hamrick 2004), compared with planting seed stock from a narrower genetic pool. Delayed regeneration may be a concern in large patches on steeper slopes as tree canopies and root systems reduce risk of landslides and debris flows.

5. Loss of old-growth forest

Only 800 acres of old forest (sites with trees >140 feet tall) burned at high severity (**Table 8**). This amounts to 14% of the 5,800 acres of old forest that burned in 2022 (**Table 8**), and only 1.5% of the total forest area burned. In western Washington, high-severity fire in large patches of old growth is a characteristic disturbance that resets forest development, creating structurally complex, early-seral forests with live and dead legacies that shape the subsequent forest in important ways (Franklin et al. 2002). However, old-growth forests are in short supply in many landscapes across western Washington due to past harvesting and land conversion (DeMeo et al. 2018, Donato et al. 2020). Loss and further fragmentation of old growth is thus generally a net-negative outcome of wildfires. To put the 800 acres in context, an estimated 180,000 acres of old-growth forest burned at high-severity in the 2020 Oregon westside fires (Reilly et al. 2022).

6. Impacts to riparian and aquatic systems

An estimated 5,950 acres of stream-adjacent forests burned in 2022. Severity proportions were almost identical to severity across the total fire extent, with 28% burning at high severity, 21% at moderate, and 51% at low (**Table 8**). Within individual fires, severity proportions also paralleled total fire extent, with high-severity occurring in 40% of the stream-adjacent acres in Bolt Creek and 58% in Nakia Creek. In contrast, 88% of stream-adjacent forest burned at low severity in Goat Rocks, and 67% in Suiattle River (**Table 8**).

These estimates provide a starting place to gauge the impacts, both positive and negative, of fires on westside riparian and aquatic systems. Although fires are infrequent in westside forests, they can have large impacts on large woody debris, productivity, shade and stream temperature, and associated fish habitat quality. Post-fire debris flows are a major source of large woody debris and sediment inputs (Benda et al. 2004, Pettit and Naiman 2007). Large fires also can have a large effect on snowpack and streamflow (Dickerson-Lange et al. 2021).

Illustrating fire spread patterns with individual fires

In order to better contextualize the aggregate effects of the 2022 wildfires in western Washington, we describe the spread patterns of individual fire events. These notable fires capture the range of fire behavior and effects in 2022, providing an indication of what is possible in the future. The forest health effects of these fires were driven by how fire behavior interacted with forest structure, fire weather, and fire operations during different periods of each fire to create patterns of low-, moderate-, and high-severity fire. These relationships can be categorized into three broad phases to inform understanding of how wildfires spread in western Washington and the resulting forest health effects for a given fire. These phases include:

1. High-spread, "blow-up" phase, where high winds, typically east winds bringing low humidity, drove large runs of high-severity crown fire. This pattern was relatively limited in 2022, only occurring in the Bolt Creek and Nakia Creek Fires. For reference, fire spread rates in these fires were orders of magnitude lower than the 2020 Labor Day Fires in western Oregon, where approximately 740,000 acres burned in a 48 hour period, and over 70% of the high-severity fire occurred in patches greater than 25,000 acres (Reilly et al. 2022).

2. Moderate-spread phase, where low fuel moistures, humidity, and moderate wind speeds resulted in significant fire spread with a range of severities. High-severity patches were generally small (<100 acres), however, and the majority of acres burned at low and moderate severity. Most of the 2022 fires exhibited this pattern for a few days or more. This pattern often occurred in steeper terrain where slope facilitated fire spread or, in some cases, where fire operations conducted burnout operations.

3. Low-spread and low-severity phase, where cooler temperatures, higher humidity, and low wind speeds limited fire spread. Burn severity was generally low with fires "skunking" in the understory. Some moderate- and high-severity fire did occur, especially in forest types that have low resistance to fire, such as young plantations or recently harvested and planted units. These fires can produce abundant smoke, even though flame lengths and fire spread are low. In many fires, burnout operations contributed to the acres burned in these conditions.

While these three phases also apply to eastside fires, they are particularly pronounced on the westside. Generally cooler weather with higher humidity and fuel moistures, denser forest canopies, and fuel types that have fewer flashy fuels (grasses and highly flammable shrubs) all contribute to lower spread rates and fewer acres burned in phase 2 and 3 periods of fires compared with eastern Washington. The factors that drive fire behavior on "blow-up" days (high winds and low humidity) are more similar between eastern and western Washington.

The Bolt Creek Fire exemplifies how these three types can unfold during a wildfire in western Washington (**Figures 8 and 9**). Driven by strong east winds, the Bolt Creek Fire blew up during its first day, September 10th, burning over 8 miles and an estimated 5,000-7,500 acres across the steep slopes of Baring Mountain and up the Eagle Creek drainage. During this phase, it burned through a checkerboard ownership of U.S. Forest Service land and approximately 2,000 acres of private, industrial forestland and other ownerships. Fire crews reached the fire within hours of when it started, but the fire was already too large to control. The fire burned mostly at high severity during this period across a range of forest structure stages, creating two high-severity patches of approximately 4,000 and 2,000 acres (**Figure 9**). Despite these intense conditions, only an estimated 40% and 55% of old and mature forest affected by the fire burned at high severity, respectively, during this period.

The fire calmed down during the next three days, but still spread at a moderate pace and burned over 1,500 acres with some moderate- and high-severity fire. Burn severity varied significantly among different structural stages, as smaller size classes tended to burn with a greater proportion of moderate and high severity (**Figure 9**). The rest of the fire (days 5-36) burned another 5,300 acres under the low-spread, low-severity pattern, although a few days of moderate spread during red flag days did occur. Some of these acres included burnout operations. During this phase, very young and young forest (<40 feet, and 40-90 feet tall) did experience some moderate- and high-severity fire, while mature and old forests were almost all low severity (**Figure 9**). Although burn severity was relatively low, smoke, road closures, and other negative social impacts continued for the duration of the fire.

In terms of the overall ecological effects of the Bolt Creek Fire, low- and moderate-severity fire potentially diversified 6,800 acres of young and mature forest. High-severity fire will likely convert 2,200 acres of mature and old-growth forest into structurally complex, early-seral habitat (**Table 8**), with another 3,700 acres of intermediate quality habitat. Much of the 5,850 acres of high-severity is in large patches on steep slopes above Highway 2 and the communities of Grotto and Baring (**Figures 8 and 9**), and may pose ongoing risk of erosion and landslides, particularly in locations with alluvial fans (See DNR Geology WALERT Report, available online). Within these large

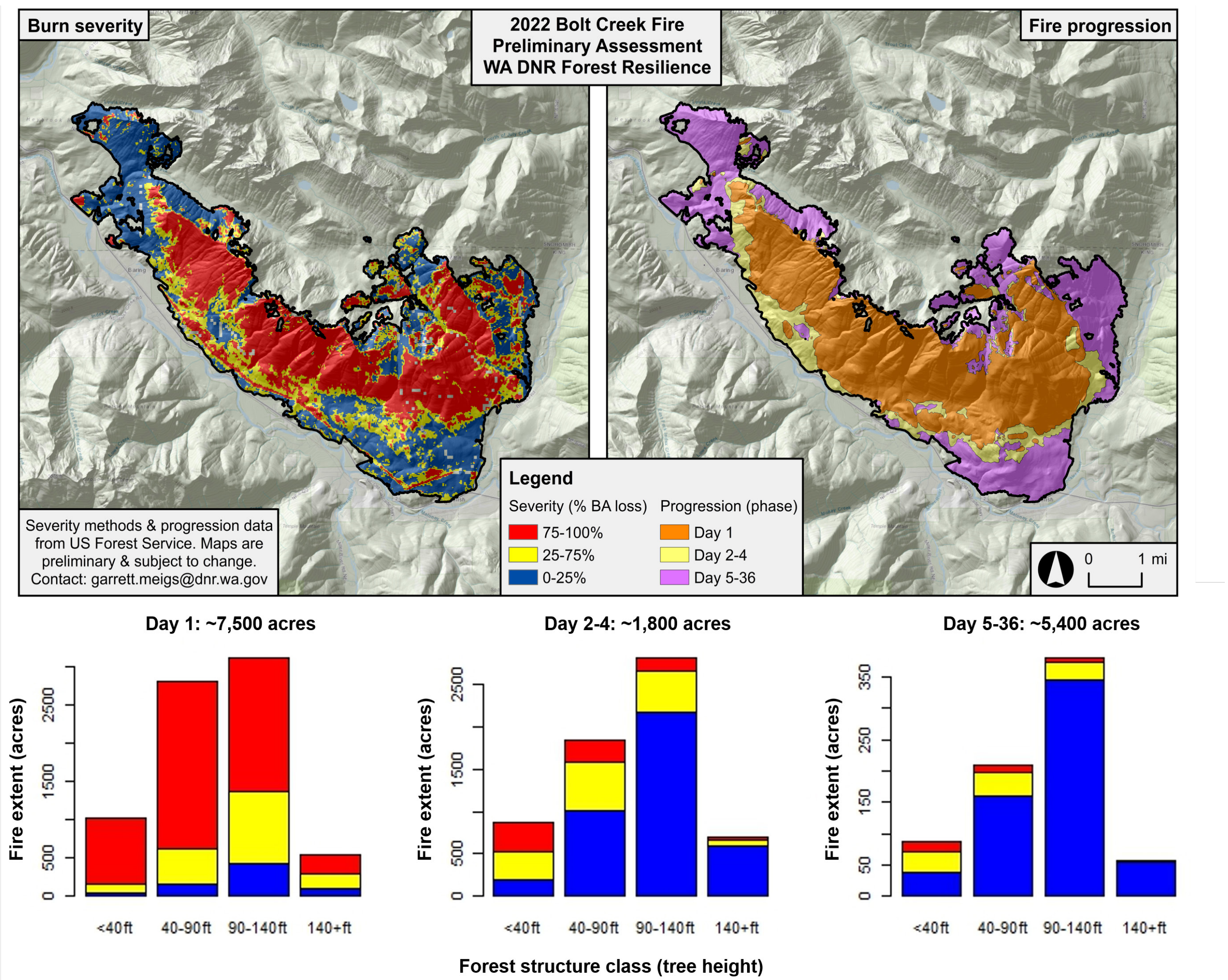

Figure 9. Bolt Creek Fire severity and spread phases across four structural stages and three burn phases. Upper left panel shows burn severity, while upper right panel shows fire progression across the three phases. Lower panels show burn severity by structural stage for each burn phase. Remotely sensed, overstory tree height was used to classify these four stages using the following thresholds: very young: <40 feet; young: 40-90 feet; mature: 90-140 feet; and old growth >140 feet. See **Appendix B** for a full description of methods. Severity estimates are preliminary and will change due to delayed tree mortality and other factors.

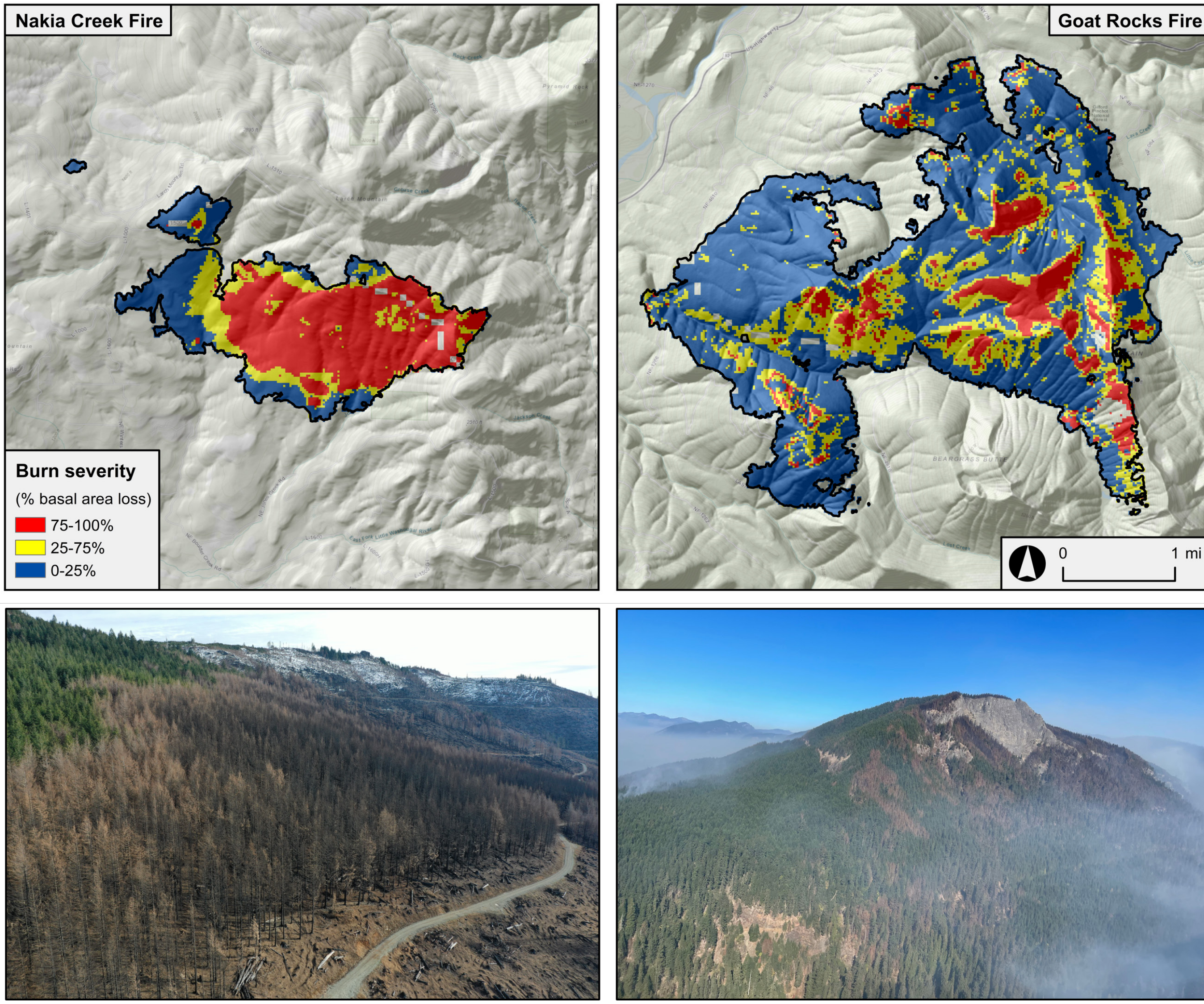

Figure 10. Example burn severity maps (top) and photos (bottom) for the Nakia Creek Fire (left) and Goat Rocks Fire (right). Severity estimates are preliminary and will change due to delayed tree mortality and other factors. Upper left: Nakia Creek Fire effects and recent harvests (photo: Brant Lindquist). Upper right: Goat Rocks Fire mosaic around Coal Creek Bluff (photo: Josh Chapman).

patches, 1,950 acres could exhibit delayed regeneration due to seed source limitation. Despite the 5,850 acres of high-severity fire, only 300 acres of old forest burned at high-severity, which equates to 22% of the 1,300 acres of old growth within the fire perimeter (**Table 8**).

Another notable fire, Nakia Creek, had a big, wind-driven spread event. For the first five days, it spread slowly at low severity and then blew up on October 17th, creating a 1,600 acre patch of high severity in one day (**Figure 10**). This wind-driven event prompted evacuations in Clark County but fortunately only lasted for a day. The fire burned another 122 acres until season-ending rains arrived one week later. Due to starting late in the season it remained a small fire under 2,000 acres. Economic and social costs of the 1,600 acre high-severity patch are significant, as the land is DNR Trustland and a municipal watershed that is a drinking water source for parts of Clark County (See DNR Geology WALERT Report, available online).

The second largest 2022 fire in western Washington, the Goat Rocks Fire, spread 2,850 acres during the red flag wind event on September 9th and 10th and prompted evacuations near Packwood. However, the fire burned with a mix of severities during this period, creating only small patches of high severity (~200 acre patches) (**Figure 10**). Prior to this red flag event, it was a small, smoldering fire in a steep, remote part of the Goat Rocks Wilderness. After the moderate spread days, it settled into the low spread pattern, although it exhibited another period of moderate spread to the south for a few days in October. A number of previously thinned units along the FS 46 road facilitated construction of a key fireline that held the fire. The Suiattle Fire near Darrington, on the other hand, burned at low spread rates for many weeks, until spreading more rapidly towards the end of the fire season. This fire had only 13% of the total area in high severity, but 8% of the old-growth forest within the fire perimeter burned at high severity.

CONCLUSIONS AND KEY TAKEAWAYS

The 2022 wildfire season had significant and widespread impacts on communities and ecosystems across Washington State. The fires affected air quality and community health, local and regional transportation networks, timber resources, recreation, and local businesses due to smoke, road closures, and evacuations. There are also ongoing risks of cascading effects including delayed tree mortality, soil stability, and debris flows. While these socio-economic impacts were extensive, the 2022 fires also had both negative and positive effects on forest health, landscape resilience, and wildfire risk reduction objectives.

This report broadens the DNR Work of Wildfire framework to encompass eastern and western Washington, which have distinct historical fire regimes and contemporary fire effects on forest health (**Table 2**). In 2022, eastern Washington experienced less forest fire than in recent major fire years, especially in dry forests. In contrast to typical patterns, fire extent in forested areas was higher in western Washington (53,600 acres) than in eastern Washington (48,000 acres). In addition, low-severity fire was relatively more abundant in western Washington than in eastern Washington (48% vs. 39% of total, respectively) (**Table 1**). The emergence of multiple, late-season fire events in western Washington is a reminder of the historical role of large fires, serves as a precursor of likely impacts in the years to come, and underscores the need for proactive strategies to protect communities and infrastructure. Here, we summarize key findings for eastern and western Washington.

Eastern Washington:

- Fires reduced fuels and fire risk on 12,150 acres that burned at low and moderate severity in dry and moist forests. This estimate is far below the total in 2021 (230,000 acres) and the historical annual average (227,650 acres). This historical estimate is a reasonable target for what is needed to reduce surface fuel loads, tree densities, and associated fire risk to forests and communities.
- In contrast to 2021, there were no large patches of high-severity fire in dry or moist forests due primarily to the limited area burned in these forests. In dry and moist forests, only 3,150 acres burned at high severity. Additionally, proportionally more moist forest burned at low severity (64% of the 8,300 total acres) than the historical average.
- Cold forests accounted for over two-thirds of fire extent, which is much higher than the estimated proportion in most recent years as well as in historical averages.
- The largest fire in eastern Washington, the Parks Fire, burned approximately 19,500 acres of cold forest, including many large high-severity patches. Although such patches are characteristic in cold forests, they add to the extensive amount of recent high-severity fire in north-central Washington, increasing the potential for conversion to young forest and non-forest vegetation types.

Western Washington:

- 2022 was the largest fire year in recent western Washington history, serving as a wake-up call to prepare for a truly large fire year that will occur at some point in the future when ignitions converge with dry fuels and high wind events.
- Most of the acres burned during periods of moderate and mild fire weather conditions, resulting in low and moderate severity. Only 27% of the total acres burned at high severity. Locations with taller tree structure corresponding to mature and old forests generally burned at lower severity.
- High-severity fire potentially initiated 14,650 acres of early-seral habitat, contributing to habitat diversity throughout the region. The quality and longevity of this habitat, however, will vary depending on the structure and composition of the forest that burned and post-fire management actions.
- More complex forest structure and higher plant diversity will likely develop in a substantial portion of the 29,650 acres of young and mature forests that burned at low and moderate severity.
- The Bolt Creek and Nakia Creek Fires experienced wind-driven “blow-up” days, where large areas burned at high severity. These fire spread events were small, however, in comparison to the 2020 Labor Day fires in Oregon.

Based on these findings and conclusions from other recent studies, we highlight the following management implications:

- In eastern Washington, 2022 was a welcome break from the large fire years that have stressed fire operations and communities over the last decade. However, the lower acreage of low- and moderate-severity fire resulted in reduced positive effects on fuels and wildfire risk reduction. Vegetation growth and fuel accumulation continue to increase risk throughout eastern Washington.
- Assessing how to maximize beneficial fire effects through prescribed fire and wildfire management operations, especially during years that have more favorable weather conditions such as 2022, is critical to achieving the goals of the DNR 20-Year Plan and the U.S. Forest Service 10-Year Wildfire Crisis Strategy in eastern Washington. Current rates of prescribed fire and other fuel reduction treatments (e.g., piling and burning) are not sufficient to reduce and maintain desired fuel levels and fire risk over time.
- Throughout western Washington, fire prevention and suppression remain important strategies, particularly where east winds or red flag conditions threaten nearby communities and infrastructure. Specific strategies during red flag conditions include shutting down power lines and recreation access, as well as pre-positioning fire suppression resources to rapidly respond to any ignitions.
- The re-emergence of large fires in western Washington underscores the importance of emergency preparedness. Primary strategies include evacuation planning for communities, home hardening and defensible space treatments, raising awareness of landslide risk and vulnerable infrastructure in fire-prone areas, and establishment of potential control lines along key roads and other features.
- Landscape-scale fuels treatments are not likely to reduce fire spread or severity during wind-driven fires in western Washington. Fuel reduction treatments may be warranted in some forests of western Washington, especially near communities, infrastructure, and vulnerable habitats.

In addition to these key findings and implications, the 2022 wildfire season demonstrated multiple lessons for ongoing and future assessments (See **Box 2**). Moving forward, we will collaborate with partners to interpret and contextualize the effects of the 2022 fires while preparing for future fire seasons. We will continue to refine our methods for mapping burn severity and delayed tree mortality. We will also continue to build out a forest health treatment database to enable a more comprehensive synthesis of how treatments influence fire behavior and effects, wildland fire operations, and subsequent fire risk and landscape resilience.

As wildfire activity continues to increase across western North America, large fire years will occur more frequently in Washington State, including in moist, westside forests. Although wildfires are an inherently blunt restoration tool with both positive and negative impacts on landscape resilience (Churchill et al. 2022), forest and fire management approaches that recognize the positive effects of wildfire will become increasingly important. Given recent warming trends and projected climate change, we are in a race against time to reduce wildfire risk to communities and to help landscapes adapt to increasing drought and wildfire activity. The only way to treat forest landscapes at scale - and maintain them over time - is by harnessing the beneficial Work of Wildfire in the appropriate places and under safe conditions, while suppressing fires that threaten resources and communities. Over time, restored landscapes will provide managers more flexibility to manage wildfire to protect communities, achieve forest health objectives with a variety of treatment tools, and maintain these fire-dependent ecosystems.

LIST OF APPENDICES

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Box 2. Ongoing efforts following the 2021 Work of Wildfire Report

The DNR Forest Health Science Team has continued to work with partners to improve methods and make results useful for decision makers, land managers, and partners. In June of 2022, we partnered with Dr. Susan Prichard and Maureen Duane from the University of Washington to conduct a workshop with over 45 participants, where we discussed the 2021 report and received invaluable feedback (see workshop summary in **Appendix C**). Based on input from this workshop and the monitoring sub-committee of the Forest Heath Advisory Committee, recent and current efforts include:

- Developing an ArcGIS online tool to rapidly identify when fires burn through treatments that are comprehensively mapped through a combination of DNR's all-lands completed treatments layer and change detection data.
- Assessing how daily spread rate affects burn severity to distinguish between treatments that burned under mild, moderate, and extreme fire weather conditions. There were not sufficient treatments that burned in 2022 to conduct this analysis, but we demonstrated spread patterns for the Bolt Creek Fire.
- Funding a University of Washington study of the drivers of burn severity in the 2021 Schneider Springs Fire, with a special focus on how past treatments affected severity. Preliminary results show that treatments reduced fire severity, even during high spread days. See King5 and NW Public Radio stories.
- Contributing to a Joint Fire Science Program proposal to expand the Schneider Springs Fire analysis to examine all treatment-fire interactions in large 2021 fires. The proposed project also includes a toolset to rapidly analyze treatment effectiveness and further improve methods to collect information on use of treatments during wildfire management operations.
- Developing a mobile questionnaire (Wildfire Interactions with Treatments survey) to assess decision-making regarding the use of forest treatments during wildfire operations. This survey connects operational actions with resulting fire outcomes to improve understanding of how treatments are utilized in practice.
- Continuing to refine methods for mapping burn severity across multiple fire years, comparing initial vs. extended assessments to evaluate delayed tree mortality and sensitivity of different satellite sensors, imagery timing, spectral indices, and classification schemes.
- Expanding capacity to conduct field-based monitoring of treatment effects, fuels, and fire effects to complement remote sensing approaches in a statewide, multi-scale monitoring framework.
- Working with Washington Geological Survey to understand post-fire effects, such as the 66 debris flow and flooding events within six 2021 wildfires, which impacted residential structures, streams, communities, and transportation.

REFERENCES

Agee, J. K. 1996. Fire ecology of Pacific Northwest forests. Island press.

Agee, J. K. 2003. Historical range of variability in eastern Cascades forests, Washington, USA. Landscape Ecology 18:725–740.

Agee, J. K., and C. N. Skinner. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management 211:83–96.

Ager, A. A., A. M. Barros, and M. A. Day. 2022. Contrasting effects of future wildfire and forest management scenarios on a fire excluded western US landscape. Landscape Ecology:1–22.

Bailey, J. D., and J. C. Tappeiner. 1998. Effects of thinning on structural development in 40-to 100-year-old Douglas-fir stands in western Oregon. Forest Ecology and Management 108:99–113.

Benda, L. E., N. L. Poff, D. Miller, T. Dunne, G. Reeves, G. Pess, and M. Pollock. 2004. The network dynamics hypothesis: how channel networks structure riverine habitats. Bioscience 54:413–427.

Boyd, R. 1999. Indians, fire, and the land in the Pacific Northwest. Oregon State University Press, Corvallis, OR.

Busby, S. U., K. B. Moffett, and A. Holz. 2020. High-severity and short-interval wildfires limit forest recovery in the Central Cascade Range. Ecosphere 11:e03247.

Cansler, C. A., S. M. Hood, P. J. van Mantgem, and J. M. Varner. 2020. A large database supports the use of simple models of post-fire tree mortality for thick-barked conifers, with less support for other species. Fire Ecology 16:1–37.

Cansler, C. A., V. R. Kane, B. N. Bartl-Geller, N. A. Povak, D. C. Churchill, P. F. Hessburg, J. A. Lutz, J. T. Kane, and A. J. Larson. 2022. Previous wildfires and management treatments moderate subsequent fire severity. Forest Ecology and Management 504:119764.

Carey, A. B. 2003. Biocomplexity and restoration of biodiversity in temperate coniferous forest: inducing spatial heterogeneity with variable-density thinning. Forestry 76:127–136.

Cassell, B. A., R. M. Scheller, M. S. Lucash, M. D. Hurteau, and E. L. Loudermilk. 2019. Widespread severe wildfires under climate change lead to increased forest homogeneity in dry mixed-conifer forests. Ecosphere 10:e02934.

Churchill, D. J., S. M. Jeronimo, P. F. Hessburg, C. A. Cansler, N. A. Povak, V. R. Kane, J. A. Lutz, and A. J. Larson. 2022. Post-fire landscape evaluations in Eastern Washington, USA: Assessing the work of contemporary wildfires. Forest Ecology and Management 504:119796.

Cramer, O. P. 1957. Frequency of dry east winds over northwest Oregon and southwest Washington. USDA Forest Service Pacific Northwest Research Station, Portland, Oregon. Research Paper, PNW-RP-24.

Davis, K. T., M. D. Robles, K. B. Kemp, et al. 2023. Reduced fire severity offers near-term buffer to climate-driven declines in conifer resilience across the western United States. Proceedings of the National Academy of Sciences 120:e2208120120.

DeMeo, T., R. D. Haugo, C. Ringo, J. A. Kertis, S. A. Acker, M. Simpson, and M. Stern. 2018. Expanding our understanding of forest structural restoration needs in the Pacific Northwest. Northwest Science 92.

Dickerson-Lange, S. E., J. A. Vano, R. Gersonde, and J. D. Lundquist. 2021. Ranking forest effects on snow storage: a decision tool for forest management. Water Resources Research 57:e2020WR027926.

Donato, D. C., J. S. Halofsky, and M. J. Reilly. 2020. Corralling a black swan: natural range of variation in a forest landscape driven by rare, extreme events. Ecological Applications 30:e02013.

Donato, D. C., J. S. Halofsky, A. M. S. Smith, D. J. Churchill, R. D. Haugo, C. A. Cansler, B. S. Kellogg, and B. J. Harvey. In prep. What makes a 'good' versus 'bad' wildfire year? Comparing contemporary wildfire years to historical fire regimes informs the restoration task in fire-dependent forests.

Dunn, C. J., C. D. O'Connor, J. Abrams, M. P. Thompson, D. E. Calkin, J. D. Johnston, R. Stratton, and J. Gilbertson-Day. 2020. Wildfire risk science facilitates adaptation of fire-prone social-ecological systems to the new fire reality. Environmental Research Letters 15:025001.

Evers, C., A. Holz, S. Busby, and M. Nielsen-Pincus. 2022. Extreme winds alter influence of fuels and topography on megafire burn severity in seasonal temperate Rainforests under record fuel aridity. Fire 5(2):41.

Fettig, C. J., A. Wuenschel, J. Balachowski, R. J. Butz, A. L. Jacobsen, M. P. North, S. M. Ostoja, R. B. Pratt, and R. B. Standiford. 2019. Managing effects of drought in California. In: Vose, James M.; Peterson, David L.; Luce, Charles H.; Patel-Weynand, Toral, eds. Effects of drought on forests and rangelands in the United States: translating science into management responses. Gen. Tech. Rep. WO-98. Washington, DC: US Department of Agriculture, Forest Service, Washington Office. 71-93. Chapter 4:71–93.

Flitcroft, R. L., J. A. Falke, G. H. Reeves, P. F. Hessburg, K. M. McNyset, and L. E. Benda. 2016. Wildfire may increase habitat quality for spring Chinook salmon in the Wenatchee River subbasin, WA, USA. Forest Ecology and Management 359:126–140.

Franklin, J. F., T. A. Spies, P. R.V., A. B. Carey, D. A. Thornburghd, D. R. Berg, D. B. Lindenmayerf, M. E. Harmond, Keeton. W.S., D. C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. Forest Ecology and Management 5624:1–25.

Fule, P. Z. 2008. Does it make sense to restore wildland fire in changing climate? Restoration Ecology 16:526–531.

Gray, A. N., and J. F. Franklin. 1997. Effects of multiple fires on the structure of southwestern Washington forests. Northwest science. 71:174–185.

Greenler, S. M., C. J. Dunn, J. D. Johnston, M. J. Reilly, A. G. Merschel, R. K. Hagmann, and J. D. Bailey. 2023. Too hot, too cold, or just right: Can wildfire restore dry forests of the interior Pacific Northwest? Plos one 18:e0281927.

Hagmann, R. K., P. F. Hessburg, S. J. Prichard, et al. 2021. Evidence for widespread changes in the structure, composition, and fire regimes of western North American forests. Ecological Applications 31(8):e02431.

Halofsky, J. S., D. C. Donato, J. F. Franklin, J. E. Halofsky, D. L. Peterson, and B. J. Harvey. 2018. The nature of the beast: examining climate adaptation options in forests with stand-replacing fire regimes. Ecosphere 9:e02140.

Hamrick, J. L. 2004. Response of forest trees to global environmental changes. Forest ecology and management 197:323335.

Harvey, B. J., M. S. Buonanduci, D. C. Donato, J. S. Halofsky, and M. J. Reilly. In prep. Characteristics, drivers, and implications of landscape burn severity in an archetypal infrequent and severe regime: insights from temperate maritime forests in northwestern Cascadia.

Haugo, R. D., B. S. Kellogg, C. A. Cansler, C. A. Kolden, K. B. Kemp, J. C. Robertson, K. L. Metlen, N. M. Vaillant, and C. M. Restaino. 2019. The missing fire: quantifying human exclusion of wildfire in Pacific Northwest forests, USA. Ecosphere 10:e02702.

Hessburg, P. F., D. J. Churchill, A. J. Larson, R. D. Haugo, C. Miller, T. A. Spies, M. P. North, N. A. Povak, R. T. Belote, P. H. Singleton, W. L. Gaines, R. E. Keane, G. H. Aplet, S. L. Stephens, P. Morgan, P. A. Bisson, B. E. Rieman, R. B. Salter, and G. H. Reeves. 2015. Restoring fire-prone landscapes: seven core principles. Landscape Ecology 30:1805–1835.

Hessburg, P. F., C. L. Miller, S. A. Parks, et al. 2019. Climate, Environment, and Disturbance History Govern Resilience of Western North American Forests. Frontiers in Ecology and Evolution 17(9):511–520.

Jager, H. I., J. W. Long, R. L. Malison, B. P. Murphy, A. Rust, L. G. Silva, R. Sollmann, Z. L. Steel, M. D. Bowen, and J. B. Dunham. 2021. Resilience of terrestrial and aquatic fauna to historical and future wildfire regimes in western North America. Ecology and Evolution 11:12259–12284.

Keane, R. E., P. F. Hessburg, P. B. Landres, and F. J. Swanson. 2009. The use of historical range and variability (HRV) in landscape management. Forest Ecology and Management 258:1025–1037.

Kemp, K. B., P. E. Higuera, P. Morgan, and J. T. Abatzoglou. 2019. Climate will increasingly determine post-fire tree regeneration success in low-elevation forests, Northern Rockies, USA. Ecosphere 10:e02568.

King, J. E. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Forestry Paper, Weyerhaeuser Forestry Research Center.

Larson, A. J., and J. F. Franklin. 2005. Patterns of conifer tree regeneration following an autumn wildfire event in the western Oregon Cascade Range. Forest Ecology and Management 218:25–36.

Larson, A. J., S. A. Jeronimo, P. F. Hessburg, J. A. Lutz, N. A. Povak, C. A. Cansler, V. R. Kane, and D. J. Churchill. 2022. Ecological principles to guide post-fire forest landscape management in the inland Pacific and Northern Rocky Mountain Regions. Forest Ecology and Management 504:119796.

Laughlin, M. M., J. D. Bakker, D. J. Churchill, M. J. Gregory, T. DeMeo, E. C. Alvarado, and B. J. Harvey. 2023. Trends in forest structure restoration need over three decades with increasing wildfire activity in the interior Pacific Northwest US. Forest Ecology and Management 527:120607.

Laughlin, M. M., L. K. Rangel-Parra, J. E. Morris, D. C. Donato, J. S. Halofsky, and B. J. Harvey. In prep. Patterns and drivers of conifer regeneration following stand-replacing wildfire in western Cascadia.

Luce, C., P. Morgan, K. Dwire, D. Isaak, Z. Holden, and B. Rieman. 2012. Climate change, forests, fire, water, and fish: building resilient landscapes, streams, and managers. Joint Fire Sciences Program, USDA Forest Service, Rocky Mountain Research Station. GTR-RMRS-290, Fort Collins, Colorado.

Meigs, G. W., M. J. Case, D. J. Churchill, C. M. Hersey, S. Jeronimo, and L. A. C. Smith. 2022. Drought, wildfire and forest transformation: characterizing trailing edge forests in the eastern Cascade Range, Washington, USA. Forestry: An International Journal of Forest Research cpac046

Meigs, G. W., C. J. Dunn, S. A. Parks, and M. A. Krawchuk. 2020. Influence of topography and fuels on fire refugia probability under varying fire weather conditions in forests of the Pacific Northwest, USA. Canadian Journal of Forest Research 50:636–647.

North, M. P., R. A. York, B. M. Collins, M. D. Hurteau, G. M. Jones, E. E. Knapp, L. Kobziar, H. McCann, M. D. Meyer, and S. L. Stephens. 2021. Pyrosilviculture needed for landscape resilience of dry western United States forests. Journal of Forestry 119(5):520–544.

Pettit, N. E., and R. J. Naiman. 2007. Fire in the riparian zone: characteristics and ecological consequences. Ecosystems 10:673–687.

Povak, N. A., D. J. Churchill, C. A. Cansler, P. F. Hessburg, V. R. Kane, J. T. Kane, J. A. Lutz, and A. J. Larson. 2020. Wildfire severity and postfire salvage harvest effects on long-term forest regeneration. Ecosphere 11:e03199.

Prichard, S. J., P. F. Hessburg, R. K. Hagmann, et al. 2021. Adapting western North American forests to climate change and wildfires: ten common questions. Ecological Applications 31(8): e02433.

Reilly, M. J., A. Zuspan, J. S. Halofsky, C. Raymond, A. McEvoy, A. W. Dye, D. C. Donato, J. B. Kim, B. E. Potter, and N. Walker. 2022. Cascadia Burning: the historic, but not historically unprecedented, 2020 wildfires in the Pacific Northwest, USA. Ecosphere 13:e4070.

Rieman, B., R. Gresswell, and J. Rinne. 2012. Fire and fish: a synthesis of observation and experience. In: Luce, Charles; Morgan, Penny; Dwire, Kathleen; Isaak, Daniel; Holden, Zachary; Rieman, Bruce. Climate change, forests, fire, water, and fish: Building resilient landscapes, streams, and managers. Gen. Tech. Rep. RMRS-GTR-290. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 159-175. 290:159–175.

Smith, R. J., A. N. Gray, and M. E. Swanson. 2020. Peak plant diversity during early forest development in the western United States. Forest Ecology and Management 475:118410.

Spies, T. A., J. W. Long, S. Charnley, P. F. Hessburg, B. G. Marcot, G. H. Reeves, D. B. Lesmeister, M. J. Reilly, L. K. Cerveny, and P. A. Stine. 2019. Twenty-five years of the Northwest Forest Plan: what have we learned? Frontiers in Ecology and the Environment 17:511–520.

Spies, T. A., P. A. Stine, R. A. Gravenmier, J. W. Long, and M. J. Reilly. 2018. Synthesis of science to inform land management within the Northwest forest plan area. USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-966:1020.

Swanson, M. E., J. F. Franklin, R. L. Beschta, C. M. Crisafulli, D. A. DellaSala, R. L. Hutto, D. B. Lindenmayer, and F. J. Swanson. 2011. The forgotten stage of forest succession: early successional ecosystems on forest sites. Frontiers in Ecology and the Environment 9:117-125.

Swanson, M. E., N. M. Studevant, J. L. Campbell, and D. C. Donato. 2014. Biological associates of early-seral pre-forest in the Pacific Northwest. Forest ecology and management 324:160–171.

Taylor, A. H., L. B. Harris, and C. N. Skinner. 2022. Severity patterns of the 2021 Dixie Fire exemplify the need to increase low-severity fire treatments in California's forests. Environmental Research Letters 17:071002.

WA DNR. 2022. 20-Year Forest Health Strategic Plan: Eastern Washington Treatment Tracking Progress Memo – November 2022. Washington State Department of Natural Resources, Forest Resilience Division, Olympia, WA.

Wine, M. L., D. Cadol, and O. Makhnin. 2018. In ecoregions across western USA streamflow increases during post-wildfire recovery. Environmental Research Letters 13:014010.

Wray, J., and M. K. Anderson. 2003. Restoring Indian-set fires to prairie ecosystems on the Olympic Peninsula. Ecological Restoration 21:296–301.

Zald, H. S., and C. J. Dunn. 2018. Severe fire weather and intensive forest management increase fire severity in a multi-ownership landscape. Ecological Applications 28:1068–1080.

Appendix A. Summary of complementary efforts related to the WA DNR Work of Wildfire Assessment (2022)

Table A1. Summary of existing programs related to post-fire assessment and forest health/fuel treatments. USFS: USDA Forest Service.

Program	Agency	Description	Link/Citation
Burn severity mapping			
BAER soil burn severity	USFS	Burned Area Emergency Response	National fire list and downloads
BARC	USFS	Burned Area Reflectance Classification	National fire list and downloads
RAVG	USGS	Rapid Assessment of Vegetation Mortality	RAVG home page
Region 6 Google Earth Engine (provides some BARC/BAER)	USFS	Google Earth Engine vegetation mortality mapping	
MTBS	USFS/ Interagency	Longer-term record of burn severity using one-year post-fire imagery (1984-2019)	MTBS home page
Fire effects and fuel treatments			
R6 fuels treatment effectiveness monitoring (FTEM)	USFS	Congressional mandate to evaluate treatments on all large fires	2021 dashboard
Fire Behavior Assessment Team (FBAT)	USFS	On-call module that measures pre-, active-, post-fire to improve knowledge about fuels, behavior, firefighter safety, etc	FBAT home page
Rapid Assessment Team (RAT)	USFS	Focus on post-fire management alternatives	
Fire perimeters (preliminary, infrared is best)	USFS	Public FTP of fire perimeters and other GIS data	WA 2022 Incidents
Fire monitoring and assessment (NWCC)	Interagency	Northwest Interagency Coordination Center, including 2021 annual report	NWCC website
Fire weather from MesoWest	University of Utah	Weather and climate data, including RAWS and iRAWS	Data interface
ICS-209 (external - all large fires, daily submission; IAP is internal)	USFS	Daily incident reports, use to connect with fire behavior, fire progression, weather, personnel to interview	NWCC PNW large fire information
Fire situation binders for WA	WA DNR	Monthly summary & outlook from WF Division	
Fire effects on slope stability	WA DNR	Wildfire-Associated Landslide Emergency Response Team (WALERT)	Home page, Example report
Fire Effects Monitoring	National Park Service		Home page
FIREMON (CBI/dNBR)	Interagency	Methods for remote sensing and field assessment (composite burn index)	CBI description

Appendix B. Detailed methods and data for the WA DNR Work of Wildfire Assessment (2022)

A. BURN SEVERITY MAPPING

To enable a comprehensive and rapid assessment of fire effects, we adapted the US Forest Service Region 6 (R6) burn severity mapping approach using Google Earth Engine. We used fire perimeters from November 2022 from the DNR Large Fires database (from the National Interagency Fire Center (https://ftp.wildfire.gov/) and pre- and post-fire Landsat-8 satellite imagery. We computed the commonly used RdNBR spectral index (details below) and classified low-, moderate-, and high-severity fire corresponding to 0-25%, 25-75%, and 75-100% tree basal area mortality with the following thresholds from Reilly et al. (2017): low: <235.195, moderate: 235.195-648.725, high: >648.725. This method is similar to the approach of the US Forest Service RAVG program (Rapid Assessment of Vegetation Conditions; https://burnseverity.cr.usgs.gov/ravg/) but allowed us to assess all fires rapidly in one workflow. Burn severity estimates were created using Google Earth Engine (Gorelick et al. 2017) and R (R Core Team 2013). Note that our burn severity maps are preliminary and do not capture delayed mortality. We anticipate that severity estimates will increase in subsequent years, especially in cold forests with fire-intolerant, thinned-barked species (Cansler et al. 2020). Moving forward, we will work with partners to update burn severity maps in the fall of 2023.

We developed this method after evaluating two primary approaches in the field during the 2021 fire season. Specifically, we considered methods from (1) R6 that compare composite satellite imagery from the year of fire with imagery the year prior to the fire and (2) the USFS RAVG program, which compares individual images pre- and immediate post-fire.

We tested both Landsat and Sentinel-2 satellite data for use in the algorithm. Sentinel imagery has a finer resolution than Landsat (20m vs. 30m), but the regressions used to estimate basal area mortality from satellite reflectance are not tuned to those data. As such, Landsat may be more accurate than Sentinel in some cases. Additionally, the two satellites are collected on different dates, meaning that cloud cover and shadows may also differ. We chose to use Landsat data for estimating 2022 severity because it produced more reasonable maps based on feedback from local land managers.

The RAVG and R6 methods have several key differences. For the RAVG approach, severity maps are based on two clear images: a pre-fire image from the year prior to the fire, and a post-fire image the year of the fire. The images are selected to have similar spectral and vegetation characteristics, to be relatively close in date, and to be clear of clouds, smoke, and other contamination. Relative differenced Normalized Burn Ratio (RdNBR; Miller and Thode 2007, Parks et al. 2014) is then calculated using the two images. Benefits of the RAVG approach include minimal effects due to climatic differences between pre- and post-fire dates, and a lack of cloud, cloud shadow, smoke, or snow contamination. Additionally, the RAVG regression equations have been modified to better fit immediate post-fire conditions, rather than year-after-fire conditions (Miller and Quayle 2015). However, the method requires much more hands-on time to calculate, and the imagery dates differ by fire, creating the potential for inconsistency among fires.

With the R6 method, RdNBR is calculated using composites of imagery from July and October of the year of the fire. Different end dates may be used, but mid-October produced the most accurate results for our analysis. This method is fast and easy to run for many fires, and is relatively consistent across all fires. Some date inconsistencies are still present due to different dates of imagery being excluded for each fire due to smoke or cloud contamination, but overall the imagery dates among fires with the R6 method are more consistent across fires than with the RAVG method. That being said, the approach is often less accurate than RAVG until several good post-fire images may be obtained, resulting in a slight delay in the availability of results. Additionally, there may be areas of falsely low severity for some time after the fire for the same reasons. Finally, the R6 method is also somewhat more prone to differences in climate and vegetation greenness between pre- and post-fire images because it does not explicitly match vegetation conditions and phenology between years.

While both RAVG and R6 burn severity maps are available externally, the DNR Forest Health Science Team created separate maps using the R6 method in order to produce consistent severity maps for all fires. USFS R6 creates severity maps for many large fires across the region, but smaller fires and fires not on USFS lands are usually excluded. Similarly, the RAVG program creates severity data for many fires across the United States, but typically only for larger fires or fires of special interest to the USFS. Additionally, because the RAVG program is responsible for maps across a much larger area, data are often not available until later in the fall or early winter. We used the R6 approach in 2021 and again in 2022 because of advantages in computational and staff time, and the need for consistent burn severity methods among individual fires.

There are several concerns with the R6 method. The method tends to slightly overestimate burn severity in lower severity zones (see 2021 methods appendix), and also improves in accuracy later in the season as more smoke- and cloud-free postfire imagery becomes available. The issue with overestimation of burn severity could potentially be reduced by applying an offset to the RdNBR values, which is a standard adjustment in similar severity calculations that allows for better comparisons among fires (Miller and Thode 2007, Parks et al. 2014). A final issue is that the burn severity estimates are based on regression equations using field data collected at least one year post-fire at sites in Washington and Oregon. Creating a new regression with data only from Washington or ecoregional subsets would potentially improve map accuracy. We continue to address several of these issues with ongoing work.

B. METRICS FOR EASTERN WASHINGTON

All metrics detailed below were assessed for the 10 largest fires (>1,000 acres total, with >100 acres of forest burned) and for all fires combined in eastern Washington.

1. Distribution of burn severity relative to historical fire regimes

Metric: Proportion of low-, moderate-, high-severity fire in dry, moist, and cold forests relative to historical ranges, with a focus on high severity in dry and moist forests.

To assess the extent to which fires moved landscapes towards landscape resilience goals, we first combined burn severity with a vegetation type layer developed for the 20-Year Plan that is based on an updated version of ILAP 2012, see Appendix B in the WA DNR Forest Health Assessment and Treatment Framework 2020 report (available online; WA DNR 2020). Non-forest areas in the vegetation type layer are from either LANDFIRE (https://landfire.gov/vegetation.php; eastern Washington) or NLCD 2019 (https://www.usgs.gov/centers/eros/science/national-land-cover-database; western Washington). Potential vegetation types (PVTs) were grouped into more general vegetation classes (dry, moist, and cold forests, plus non-forest vegetation) (**Table B1**). The observed proportions of low-, moderate-, and high-severity fire for dry, moist, and cold forest were then calculated for each fire.

Ranges for historical reference fire severities (5th percentile, 50th percentile, and 95th percentile) were calculated for dry, moist, and cold forests for each fire using values from Haugo et al. (2019), which are based on LANDFIRE 2016 Biophysical Settings Review (www.landfirereview.org) and refined simulation methodology from Blankenship et al. (2015). We used a crosswalk from Haugo et al. (2019) to match our PVTs to Landfire Biophysical Settings. These values are provided in **Table B1**. For fires with more than one PVT within a vegetation type (e.g., dry ponderosa pine and dry mixed-conifer PVTs, which are both in the Dry Forest vegetation type), we calculated weighted averages for the historical ranges using the area of each PVT within the fire perimeter. The final step was to compare the observed severity proportions for each fire by vegetation type with the historical ranges. Non-forest types (shrublands, grassland) were not included in this analysis.

2. Reduction of surface fuels and tree densities

Metric: Acres of low- and moderate-severity fire in dry and moist forests.

We calculated the total acres that burned at low- and moderate-severity in dry and moist forests. See previous sections for details on the creation of burn severity and vegetation type rasters.

3. Simplification of landscape pattern from large, high-severity patches

Metric: Acres of medium to large (100+ acres) high-severity patches in dry and moist forests.

We calculated the amount of high-severity acres in large (>1,000 acres), medium (100-1,000 acres), and small patches (<100 acres) for moist and dry forests. Patches were generated from a combined raster of the 30-m resolution burn severity and vegetation type data described in the previous section using an 8-pixel nearest neighbor rule. High-severity dry and moist forest pixels were combined for this analysis. To avoid artificially breaking up high-severity patches by forest type, cold forest pixels within these patches were also included to delineate patches and calculate patch sizes. However, only dry and moist forest pixels were counted when calculating the number of acres in each patch size bin (large, medium, small).

4. Potential forest conversion due to tree seed source limitation

Metric: Acres of high severity >500 feet from an unburned, low-, or moderate-severity pixel.

We calculated the amount and proportion of acres in high-severity patches greater than 150 meters (500 feet) from residual live trees. This distance is a common threshold for seed dispersal beyond which tree regeneration drops off, particularly for ponderosa pine (Stevens-Rumann and Morgan 2019, Povak et al. 2020). We used the high-severity patches described in the previous section, calculating the distance to the nearest unburned, low-, or moderate-severity pixel. Non-forest pixels were excluded based on a forest mask (WA DNR 2021). We summed the area of pixels with values >150 m to generate the total acres. Distances were calculated from pixel center to pixel center.

5. Loss of large trees in open- and closed-canopy forests

Metric: Acres of large trees burned at high severity.

We tabulated the severity of forested areas with large trees (greater than 20” in diameter) using LiDAR information that covers most of eastern Washington. Areas with large trees were mapped using a 95th percentile height (P95) layer (30-m pixel resolution) with a height cutoff of 100 feet. Prior modeling using tree lists from over 600 field plots (location mapped with high accuracy GPS) in eastern Washington indicated that P95 values of ≥100 feet generally correspond with an overstory quadratic mean diameter (QMD) of ≥20” from field plots (WA DNR 2021). An overstory QMD of 20” is a common definition of large tree structure in eastern Washington. Overstory QMD is calculated using the top 25th percentile of trees by diameter in a plot. In areas where LiDAR data were not available, we used QMD of trees greater than 6” diameter from WA DNR’s forest inventory (based on Digital Area Photogrammetry using NAIP imagery; see WA DNR 2021) or QMD of the top 25th percentile of trees by height from GNN (Ohmann et al. 2011).

6. Impacts to riparian and aquatic systems

Metric: Burn severity in stream-adjacent forests.

We mapped stream-adjacent forests using the WA DNR stream layer with buffers of 250 feet for rivers, 150 feet for fish bearing streams, 75 feet for non-fish bearing, and 50 feet for intermittent. The distances are not from DNR or USFS regulatory buffers, but rather are based on forest-stream ecological interactions. Burn severity layers described above were used to tabulate the number of stream adjacent acres in each severity class (low, moderate, high).

C. METRICS FOR WESTERN WASHINGTON

All metrics detailed below were assessed for the 13 largest fires (>1,000 acres total burned) and for all fires combined in western Washington.

1. Distribution of burn severity relative to forest structure stages

Metric: Proportion of low-, moderate-, high-severity fire in very young, young, mature, and old forest structural stage.

Burn severity across different structural stages provides the base data for assessing the forest health effects of westside fire (Donato et al. 2020, Reilly et al. 2022). We classified pre-fire forest structure into four stages based on remotely sensed height data using 95th percentile height (P95) from 2019 Digital Area Photogrammetry (DAP) data that DNR produces from NAIP imagery (Strunk et al. 2019). GNN data from 2017 were used (Ohmann et al. 2011) where DAP was not available due to the lack of a LiDAR ground model. Height thresholds were used to define four different structural stages: very young (<40 feet), young (40-90 feet), mature (90-140 feet), and old forest (>140). This simple approach works well to characterize structural conditions and developmental stage (King 1966, Franklin et al. 2002), although management history, ownership, and site productivity create significant variability. These stages are similar to the six stages used by Reilly et al. (2022), except that the "Sparse", "Open", and "Sapling/Pole" from Reilly et al. (2022) are represented by the "very young" class for this analysis.

Height thresholds were based on expert opinion and assessment of P95 values in areas with known age class information. Height was used instead of tree diameter, as height is more closely related to age in westside forests (King 1966). Canopy cover was not included as the vast majority of forested that burned had high canopy cover (60%+) prior to the fire. The very young class was the only stage that had significant area with low to moderate cover. These areas were mostly recently harvested sites, young plantations, or canopy openings.

Broadleaf presence from GNN was also examined to determine if areas dominated by broadleaf species (red alder, big leaf maple, black cottonwood, willow species, etc.) burned at different severities than conifer dominated areas. Many of these acres were in recently harvested areas, however, and so distinguishing cover from broadleaf trees vs. shrubs proved challenging. This analysis may be pursued in future years if better tree species composition layers become available.

2. Diversification of dense, mid-seral forest

Metric: Acres of low- and moderate-severity fire in dense, young and mature forests.

See explanation in #1 above for information on how forest structural stages were mapped.

3. Creation of early-seral habitat

Metric: Acres of high-severity fire in mature and old-growth forest (structurally complex habitat) and very young and young forest (diverse habitat).

See explanation in #1 above for information on how forest structural stages were mapped.

4. Delayed tree regeneration due to seed source limitation

Metric: Acres of high-severity fire >500 feet from an unburned, low-, or moderate-severity pixel and largest patch index of high-severity fire.

We used the same methods here as in eastern Washington.

5. Loss of old-growth forest

Metric: Acres of old forest burned at high severity, as well as proportion of total.

See explanation in #1 above for information on how forest structural stages were mapped.

6. Impacts to riparian and aquatic systems

Metric: Burn severity in stream-adjacent forests.

We used the same methods here as in eastern Washington.

Additional western Washington method: acres burned and severity by burn period

In order to assess the relationships between spread rates and severity and to identify acres that burned on wind-driven "blow-up" days vs. low-moderate spread days, fire progression shapefiles were downloaded from the NIFC website for each fire in western Washington. The "IR_Data_Heat_Perimeter" shapefiles were used. Burn periods ranged from 1 to 10+ days, as fire progression shapefiles are not available for each day. The fire extent during each burn period was calculated, as well as the severity. This approach allowed us to compare severity proportions during different burn phases of a fire. In future reports, we intend to incorporate this information into our evaluations of treatment effectiveness. While not an exact measure of fire weather conditions, the number of acres burned during a day provides a good indication of the fire weather conditions under which a treatment burned. The information can distinguish between treatments that burned under mild, moderate, and intense fire weather conditions.

D. REFERENCES

Blankenship, K., L. Frid, and J. L. Smith. 2015. A state-and-transition simulation modeling approach for estimating the historical range of variability. AIMS Environmental Science 2:253–268.

Cansler, C. A., S. M. Hood, P. J. van Mantgem, and J. M. Varner. 2020. A large database supports the use of simple models of post-fire tree mortality for thick-barked conifers, with less support for other species. Fire Ecology 16:1–37.

Donato, D. C., J. S. Halofsky, and M. J. Reilly. 2020. Corralling a black swan: natural range of variation in a forest landscape driven by rare, extreme events. Ecological Applications 30:e02013.

Gorelick, N., M. Hancher, M. Dixon, S. Ilyushchenko, D. Thau, and R. Moore. 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote sensing of Environment 202:18–27.

Haugo, R. D., B. S. Kellogg, C. A. Cansler, C. A. Kolden, K. B. Kemp, J. C. Robertson, K. L. Metlen, N. M. Vaillant, and C. M. Restaino. 2019. The missing fire: quantifying human exclusion of wildfire in Pacific Northwest forests, USA. Ecosphere 10:e02702.

King, J. E. 1966. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Forestry Paper, Weyerhaeuser Forestry Research Center.

Miller, J. D., and B. Quayle. 2015. Calibration and validation of immediate post-fire satellite-derived data to three severity metrics. Fire Ecology 11:12–30.

Miller, J. D., and A. E. Thode. 2007. Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). Remote Sensing of Environment 109:66–80.

Ohmann, J. L., M. J. Gregory, E. B. Henderson, and H. M. Roberts. 2011. Mapping gradients of community composition with nearest-neighbour imputation: extending plot data for landscape analysis. Journal of Vegetation Science 22:660–676.

Parks, S. A., G. K. Dillon, and C. Miller. 2014. A new metric for quantifying burn severity: the relativized burn ratio. Remote Sensing 6:1827–1844.

Povak, N. A., D. J. Churchill, C. A. Cansler, P. F. Hessburg, V. R. Kane, J. T. Kane, J. A. Lutz, and A. J. Larson. 2020. Wildfire severity and postfire salvage harvest effects on long-term forest regeneration. Ecosphere 11:e03199.

R Core Team, R. 2013. R: A language and environment for statistical computing.

Reilly, M. J., A. Zuspan, J. S. Halofsky, C. Raymond, A. McEvoy, A. W. Dye, D. C. Donato, J. B. Kim, B. E. Potter, and N. Walker. 2022. Cascadia Burning: The historic, but not historically unprecedented, 2020 wildfires in the Pacific Northwest, USA. Ecosphere 13:e4070.

Stevens-Rumann, C. S., and P. Morgan. 2019. Tree regeneration following wildfires in the western US: a review. Fire Ecology 15:1–17.

Strunk, J., P. Packalen, P. Gould, D. Gatziolis, C. Maki, H.-E. Andersen, and R. J. McGaughey. 2019. Large Area Forest Yield Estimation with Pushbroom Digital Aerial Photogrammetry. Forests 10:397.

WA DNR. 2020. Forest health assessment and treatment framework (RCW 76.06.200). Washington State Department of Natural Resources, Forest Resilience Division, Olympia, WA.

WA DNR. 2021. GIS Data Dictionary: Public data for 20-Year Forest Health Strategic Plan for Eastern Washington. Washington State Department of Natural Resources, Forest Resilience Division, Olympia, WA.

Table B1. Historical burn severity distributions for potential vegetation types of eastern Washington. Source: Haugo et al. (2019), based on LANDFIRE 2016 Biophysical Settings Review (www.landfirereview.org) and refined simulation methodology from Blankenship et al. (2015). ILAP: Integrated Landscape Assessment Project (https://ecoshare.info/ilap/about-ilap/).

Potential Vegetation Type	Forest Type	ILAP Code 2012	Fire Regime Group	Burn Severity Percentiles								
				Low			Moderate			High		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
Oak Pine	Dry	WEC_fop	I	0.75	0.8	0.86	0.01	0.02	0.03	0.12	0.17	0.23
Ponderosa Pine	Dry	WEC_fpd	I	0.68	0.76	0.83	0.13	0.19	0.24	0.03	0.05	0.08
Dry Mix Conifer	Dry	WEC_fmd	I	0.61	0.67	0.72	0.18	0.21	0.25	0.06	0.11	0.18
Moist Mix Conifer	Moist	WEC_fmm	III	0.2	0.24	0.29	0.39	0.5	0.61	0.16	0.26	0.37
Silver Fir	Cold	WEC_fsi	III	0	0	0	0.42	0.54	0.65	0.35	0.46	0.58
Mtn Hemlock	Cold	WEC_fmh	V	0.11	0.17	0.24	0.21	0.28	0.36	0.46	0.55	0.64
Subalpine Parklands	Cold	WEC_fal	III	0	0	0	0.73	0.81	0.9	0.1	0.19	0.27
Ponderosa Dry	Dry	WNE_fpd	I	0.67	0.75	0.83	0.14	0.19	0.25	0.04	0.06	0.1
Dry Mixed Conifer	Dry	WNE_fdd	I	0.62	0.68	0.72	0.18	0.21	0.25	0.06	0.11	0.18
NRM Mixed Conifer	Moist	WNE_fcm	III	0.2	0.24	0.29	0.41	0.51	0.61	0.15	0.24	0.39
W Red Cedar	Moist	WNE_frn	III	0	0	0	0.48	0.56	0.66	0.34	0.44	0.52
Subalpine - Lodgepole	Cold	WNE_fes	IV	0	0	0	0.06	0.17	0.28	0.72	0.83	0.94
Subalpine - Spruce	Cold	WNE_fcd	IV	0	0	0	0.05	0.18	0.35	0.65	0.82	0.95
Subalpine Fir	Cold	WNE_faf	IV	0.07	0.11	0.15	0.08	0.13	0.17	0.68	0.76	0.81
Subalpine Parklands	Cold	WNE_fal	III	0	0	0	0.05	0.18	0.35	0.65	0.82	0.95
Xeric Ponderosa pine	Dry	WBM_fxp	III	0.28	0.34	0.43	0.39	0.47	0.56	0.12	0.19	0.28
Dry Ponderosa pine	Dry	WBM_fdp	I	0.69	0.75	0.82	0.14	0.19	0.24	0.03	0.05	0.08
Dry Douglas-fir	Dry	WBM_fdd	I	0.62	0.68	0.75	0.18	0.21	0.25	0.05	0.11	0.18
Warm-Dry Grand fir	Dry	WBM_fdg	I	0.62	0.68	0.75	0.18	0.21	0.25	0.05	0.11	0.18
Cool-Moist Grand fir	Moist	WBM_fcm	III	0.19	0.24	0.29	0.43	0.51	0.59	0.16	0.25	0.34
Cold-Dry Subalpine fir	Cold	WBM_fcd	IV	0	0	0	0.05	0.16	0.31	0.69	0.84	0.95

Appendix C. 2021 WA DNR Work of Wildfire Workshop Summary

WORKSHOP SUMMARY
Work of Wildfire Assessment – 2021 Wildfire Season

Washington Department of Natural Resources – June 3, 2022

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Introduction

In March of 2022, the Washington Department of Natural Resources (DNR) released its first Work of Wildfires Assessment for the 2021 wildfire season in eastern Washington. During the 2021 wildfire season, a total of 679,761 acres burned in eastern Washington State and of this, 463,345 acres were forested. The report assessed how these wildfires impacted landscape restoration and wildfire risk reduction goals in the context of the 20-year Forest Health Strategic Plan for eastern Washington.

The 20-year plan details a strategy for increasing forest health and resilience to future drought, insects and disease, and wildfires. Although proactive treatments are a priority, the reality is that wildfires generally burn much greater land area than is currently treated by land managers. Wildfires create a range of impacts, from high severity fires that are potential catalysts for vegetation change, particularly within a rapidly changing climate, and low and moderate severity effects, which in some locations may be contributing to long-term forest health and fuel reduction objectives.

In its first year, the Work of Wildfires rapid assessment evaluated patterns of fire severity and the relative impacts of low, moderate, and high severity fire across major forest types of eastern Washington. For the 14 largest fire events, the rapid assessment also evaluated five metrics related to wildfire outcomes, including 1) proportion of low, moderate, and high severity fire in both dry and moist forests, 2) acres burned as high severity fire in large, medium and small patches, 3) proportion of burned area that created potential seed source limitations for tree regeneration, 4) large tree mortality through lidar analysis, and 5) proportion of low, moderate and high severity fire in fires within riparian and aquatic corridors. Some of these large fires burned substantial area within DNR Priority Landscapes and will require an update to landscape evaluations that guide future planning objectives. The 2021 Cedar Creek fire was selected for this more detailed analysis and reporting.

In June of 2022, DNR partnered with the FLAME lab at the University of Washington to organize a webinar related to the report. The main goal of webinar was to gather feedback from researchers, fire managers, and fuels specialists on the methods and results of this first rapid assessment, focusing specifically on applications to treatment tracking and future monitoring and research. Over 55 individuals were invited to join the web-based workshop, and a total of 48 participated. A list of participants and their affiliations is provided in below.

The 2-hr workshop provided an overview of the DNR Work of Wildfires and then hosted a series of regional lightning talks by Cody Desatel (Confederated Tribes of the Colville), Chris Dunn (Oregon State University), Jason McGovern (US Forest Service), Sam Steinshouer (WA DNR), and Jen Watkins (WA DNR). In the second hour of the workshop, we hosted a set of small-group breakout sessions guided by the following prompts:

1) Feedback on the DNR Work of Wildfires rapid assessment:
- What do you think of the approach used to estimate the positive, negative, and other work of wildfire (severity x forest type, high-severity patch size, large tree mortality)?
- How do you see you or your organization using this information?

2) Integrating the work of wildfires into treatment tracking:
- What are some limitations of rapid assessment methods for formal treatment tracking?
- What additional data or information should be incorporated (field observations, short- vs. long-term fuel dynamics, first vs. second entry fires or treatments)?

3) Research needs:
- What are some recommendations for future research that can guide future assessments and evaluation of the work of wildfires?

A recording of the webinar is available online: WOW Workshop Recording. Powerpoint slides and other resources provided by the speakers are also available for download:
WOW slides and resources.

Regional Lightning Talks

Cody Desautel, Natural Resources Director, Confederated Tribes of the Colville
Since 2015, wildfires have impacted nearly 700,000 of the 1.4 million acres on the Colville Reservation. Not all of the fire effects have been high-severity; some burned areas can be counted as fire treatments. Over the past decades, the Confederated Tribes of the Colville have shifted their forest management approach to early seral/fire resilient species, creating more openings on the landscape. Cody showed the Summit Trail Fire BARC map, which did not have much high severity fire. Looking forward, in areas that have not burned, the management focus will be on how to reduce ground surface fuels in near term. In areas that have burned, the focus is on how to accomplish post-fire restoration work (salvage, planting). Their forest management plan has specific targets for percentages in each respective forest type and how much of each of these types they want on the landscape to achieve various management goals (water quality, big game habitat, cultural plants, etc.). In terms of adaptive management, the Tribes don't know what climate change holds, but they know that it is worse than predicted. What they see from a suppression perspective is only going to get worse with fewer firefighters, longer fire seasons, more WUI and more demand for resources. Proactive management to reduce post-fire effects is how we will likely shift our management to focus on this vs. traditional timber production model.

Chris Dunn, Assistant Professor, Oregon State University
Chris provided a brief overview of fire management applications across the western US. He emphasized the importance of wildfire events in the context of future fire management. After a fire occurs, what does it mean for future fire potential and control or use of fire later on? What features are fire management agencies using to contain fires? A copy of his presentation on Potential Control Locations is available online: CDunn PCL Metric of WOW and Counterfactual.pdf.

Jason McGovern, Regional Fuels Coordinator, USFS Region 6 Fuels Program
The FACTS database is the USFS activity tracking system used to track forest regeneration, harvest, stand exams, noxious weed management and other USFS land management activities. The database is used internally and not publicly available. Recent wildfires are tracked as "unplanned natural ignitions." For lightning and other fires not caused by humans, an initial post-fire assessment is made on fire effects (severity), basal area or canopy cover loss, invasives, exotics, soil damage, etc. For large fires, defined as > 300 acres, fire effects are binned into the proportion of area that can be considered as a treatment (i.e., moved closer to desired conditions) or negative impact (i.e., high severity fire, invasives). Human-caused fires are not currently included in FACTS and no longer-term changes in fuels from post-fire tree mortality or subsequent insect/disease agents are included. More details can be found within the FACTS guidebook:

Sam Steinshouer, State Lands Forest Health Program Manager, WA DNR
State Lands is responsible for managing Washington state lands held in trust for a variety of beneficiaries. As with any ownership, these lands are at risk of impact due to wildfire. Once the smoke clears, the State Lands division uses a spatial and tabular forest management database called Land Resource Manager – this database allows managers to schedule specific activities and track units over time. Wildfire impacts cover burned timber that is potentially available for salvage and burned young stands that may need reforestation. The State Lands division is also considering tracking burned areas that may be used for future control lines and/or shaded fuel breaks. Understory burns are also being considered as a potential treatment accomplishment, but they are still working out evaluation metrics. However, fire is just

one of many variables considered in forest management, and treatment tracking requires staff time, which is often limited based on other priorities.

Jen Watkins, Acting Division Manager for Forest Resilience Division, WA DNR
Washington State has a legal requirement to provide fuel treatment tracking, which can be used for long-term restoration planning and also by wildland fire operations during wildfire incidents. The Washington DNR Forest Resilience Division recently created the Forest Health Tracker. In creating a map-based dashboard, the development team recognized that tabular summaries are not as helpful to decision makers as actual maps that depict the spatial extent of treatments and wildfires within areas of specific interest. Jen provided an overview of the tool and current functionality. The hope is that a broad range of agencies and decision makers will use the tool. A remaining challenge is to create a language of what treatments and impacts they are tracking and to integrate datasets from different federal, state and tribal organizations.

Break Out Session Takeaways

Overall, the feedback on the WOW Rapid Assessment was extremely positive. Workshop participants discussed the value of these assessments and how we need a longer-term plan for incorporating the work of wildfires into treatment tracking, prioritization, and use of past wildfires in operations. The following are key takeaways (**in bold**) that summarize participant recommendations (bulleted items).

1. Need for both rapid and longer-term assessments

- Given that post-fire mortality and fuel succession is a reality, immediate treatment effects offer only a short-term assessment of the work of wildfires. Fires are a trigger that start a cascade of events.
- It would be good to incorporate these methods into USFS rapid postfire assessments.
- Consider adding an update with extended fire severity mapping for the previous year in annual reports (e.g. add section on extended 2021 severity in report on 2022 fires). This could include updates from agencies on fire effects and post-fire management actions for a specific fire that would be based on field observations and more time to assess the work of a particular fire.
- On-the-ground assessment and monitoring is needed to compliment remotely sensed information. Need to devote resources to make this happen.
- Longer-term monitoring and assessment of multiple years are also needed. For example, within the 2014 Carlton Fire there is a need for longer-term evaluation and projections for tree regeneration, next priorities for vegetation and fuels management.

2. Need to refine definitions of beneficial vs. damaging fire effects

- More specific metrics as opposed to normative language around beneficial or damaging fire effects. Good fires and bad fires are overly simplistic bins. Depends on what you care about - habitat, post-fire regeneration, fuel reduction. Maybe good and bad can be split into good/bad among several metrics.
- More holistic view of fire effects and outcomes: applications to carbon stability, wildfire habitat, various resources.
- Social values should be incorporated.
- Agencies need to take a hard look at whether fire met landowner objectives. Field work is needed in coordination with remote sensing analysis.
- Because each agency has its own reporting needs and complexities, it is a challenge to establish uniform metrics. Reporting fires as accomplishment work, meeting targets, is tricky.

- Need to also incorporate fire management perspective in addition to post-fire vegetation and ecological assessments. Integration of both is more meaningful to the public and policy makers.
- Post-season workshops with managers are necessary to look back at fires from previous years and effects on resources.
- Why is it assumed high-severity fire isn't restorative? Some high-severity fire is good. Could high severity fire be more finely tuned from a restoration perspective? How can assessments incorporate the deficit of early seral habitat?

3. Improve ability to assess treatment effectiveness

- Consistent, all-lands information on treatments is needed that is readily available online and regularly updated. Treatment information that goes past as far as possible is needed.
- Past wildfires should be incorporated into treatment layers/database, so effects of past fires can be assessed (fires that stop at old fire perimeters and reburned areas).
- Need a comprehensive analysis of treatments that burned, particularly comparing prescribed fire and other treatments, to learn for future treatments and fire operations.
- Need ways to incorporate weather conditions under which different treatments burned – this is important and can affect "luck" as to whether forest conditions or treatments were successful.
- How do older treatments (especially the time since treatment) interact with contemporary fires – there's still lots to learn on treatment, and treatment window, efficacy.

4. Longer term assessment of work of low- and moderate-severity fire

- Wildfires sometimes do the work of fuel reduction treatments by thinning forests and reducing surface fuels.
- What problems does first-entry wildfire create 10 years later when fire-killed trees start falling? Need for longitudinal treatment tracking over many years.
- Site-specific post-fire management planning and monitoring is needed to better understand surface fuel and vegetation trajectories and future treatment needs (e.g., reforestation, subsequent thinning/prescribed fire, use of burned areas in wildland firefighting operations).
- Once we get one year post fire, agencies should be figuring out how to treat again within 5-15 years, depending on site productivity and post-fire fuel complexes.

5. Better incorporate the effect of fire management decisions on fire outcomes and use of treatments

- For example, where backburning was done as a type of prescribed burn or outcomes associated with patiently letting fire perimeters burn, etc.
- Track how fire operations used past fire perimeters to manage fires, not just treatments.
- Better incorporation of fire operations (e.g., innovative suppression on Cedar Creek Fire).

6. Improvements to burn severity mapping

- Consider setting regionally consistent burn severity thresholds for differing vegetation types, instead of piecemeal thresholds for low-, moderate-, and high-severity classifications.
- Increasingly open forests and reburns could confound fire severity assessments.
- How to capture delayed mortality via. remote sensing?
- Need to calibrate timing of images to structural conditions and phenology.
- Need to improve models with more extensive field plots.
- Add structural information to severity: Severity does not take into account what used to be there. It is therefore difficult to assess the work of beneficial or departure.

- Develop better probabilistic models to predict structural change based on pre-fire conditions and severity, and delayed mortality especially for large trees. This would improve accuracy of RAPID assessments.

7. Prescribed fire

- How does prescribed fire fits with assessment data (i.e., how can information be leveraged to inform where to conduct prescribed fire treatments)?
- Provide guidance to regions and partners of where to think about implementing prescribed fires WOWRAP offers opportunity to complement existing analyses of drivers of fire severity (forest structure, biophysical gradients).

8. Reburns

- Better understanding of the drivers of high-severity fire - can we learn from these outcomes for future fire seasons and develop a more nuanced narrative about why and how fires burn?
- Much of the focus of this report was on low elevation forests and the work of low and moderate severity fires. A next version could be enhanced by greater focus on cold forests and the work of high severity fire mosaics.

List of workshop participants and affiliations

Name	Affiliation	Role
Ernesto Alvarado	University of Washington School of Environmental and Forest Sciences	Participant
Jon Bakker	University of Washington School of Environmental and Forest Sciences	Participant
Alina Cansler	University of Washington School of Environmental and Forest Sciences (now University of Montana)	Participant
Michael Case	Forest Ecologist, The Nature Conservancy Washington	Participant
Matt Castle	Deputy Fire Staff, USFS Region 6	Participant
Derek Churchill	WA DNR Forest Resilience Division Planning, Science, & Monitoring Team	WOW team
Robyn Darbyshire	Regional Silviculturist, USFS Region 6	Participant
Tom DeMeo	Ecologist, USFS Region 6	Participant
Cody Desautel	Natural Resources Division Director, Confederated Tribes of the Colville	Presenter - lightning talk
James Dickinson	Washington State Fire Ecologist, Bureau of Land Management	Participant
Daniel Donato	WA DNR Natural Resource Scientist	Participant
Aleksander Dozic	WA DNR Forest Resilience Division Planning, Science, & Monitoring Team	WOW team
Maureen Duane	University of Washington School of Environmental and Forest Sciences	Organizer
Chris Dunn	Oregon State University College of Forestry	Presenter - lightning talk
Matthew Eberlein	Prescribed Fire Manager, Washington Department of Fish and Wildlife	Participant
Tucker Furniss	Ecologist, Wenatchee Forest Sciences Lab, USFS PNW Research Station	Participant
Richard Gardner	Integrated Vegetation Staff, USFS Region 6	Participant
Joshua Halofsky	WA DNR Natural Resource Scientist	Participant
Brian Harvey	University of Washington School of Environmental and Forest Sciences	Participant
Ryan Haugo	Director of Conservation Science, The Nature Conservancy - Oregon	Participant
Van Kane	University of Washington School of Environmental and Forest Sciences	Participant
Kerry Kemp	Forest Ecologist, USFS Region 6	Participant
Allen Lebovitz	WA DNR Wildland Fire and Forest Resiliency Liaison	Participant
Jason McGovern	Regional Fuels Coordinator, USFS Region 6 Fuels Program	Presenter - lightning talk
Garrett Meigs	WA DNR Forest Resilience Division Planning, Science, & Monitoring Team	WOW team
Jim Menakis	National Fire Ecologist, USFS Washington Office	Participant
Kerry Metlen	Forest Ecologist, The Nature Conservancy Oregon	Participant
Colton Miller	University of Washington School of Environmental and Forest Sciences	Participant
Cameron Naficy	Landscape Ecologist, USFS Blue Mountains Area Ecology Program	Participant
Michael Norris	WA DNR Forest Health Fire Ecologist	Participant
James Pass	Forest Silviculturist / Timber Program Manager, USFS Region 6	Participant
David Peterson	Research Forester, USFS Wenatchee Forest Sciences Lab, PNW Research Station	Participant
Nicholas Povak	Research Ecologist, Pacific SW Research Station	Participant
Susan Prichard	University of Washington School of Environmental and Forest Sciences	Presenter - facilitator
Don Radcliffe	University of Washington School of Environmental and Forest Sciences	Participant
Matthew Reilly	Ecologist, PNW Research Station	Participant
Shane Robson	Deputy Fire Staff - Fuels, USFS Region 6	Participant
Frankie Romero	Fire Use and Fuels Program Manager, USFS	Participant
Aaron Rowe	Forest Fuels and Prevention Specialist, USFS Region 6	Participant
Kabindra Shahi	Lake County Resources Initiative	Participant
Annie Smith	WA DNR Forest Resilience Division Planning, Science, & Monitoring Team	WOW team
Sam Steinshouer	WA DNR State Lands Forest Health Program Manager	Presenter - lightning talk
Jens Stevens	Program Lead for Wildland Fire and Fuels, USFS Washington Office	Participant
Max Wahlberg	Ecologist, USFS Region 6	Participant
Jen Watkins	Acting Division Manager for Forest Resilience Division	WOW team
Pete Wier	Forester, USFS Region 6	Participant
Kate Williams	WA DNR Prescribed Fire Planner	Participant