NATURAL RESOURCES

WILDFIRE SEASON 2023 WORK OF WILDFIRE ASSESSMENT

Forest Health Science Team
Forest Resilience Division

This report provides a rapid evaluation of the effects of the 2023 wildfires on forest landscape resilience and wildfire risk reduction objectives across Washington State

JUNE 2024

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Contents

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Wildfire Season 2023 - Work of Wildfire Assessment

EXECUTIVE SUMMARY

In 2023, wildfire extent was relatively low compared to recent years, but there were substantial impacts on social, economic, and ecological values throughout Washington state. As in 2022, the socio-economic effects of the 2023 fires were in many ways more significant than the ecological effects. Smoke impacted air quality across the Pacific Northwest, affecting health, livelihoods and outdoor activities. Additionally, structure losses, evacuations, and road closures impacted communities, especially in the Columbia Gorge and Spokane County.

In 2017, the Washington State Department of Natural Resources (DNR) launched the 20-Year Forest Health Strategic Plan: Eastern Washington to accelerate work on landscape-scale wildfire risk reduction, restoration, and climate adaptation across all lands. Over the ensuing 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 assesses the work of wildfire - i.e., the degree to which fire effects are consistent with landscape resilience and wildfire risk reduction objectives - of the 2023 fire season, building on similar reports on 2021 and 2022. 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. Key findings from this assessment include the following:

Statewide summary

Across Washington, large fires affected 174,300 total acres and 44,000 forested acres. These totals are relatively low compared to recent record-breaking years, including 2015 and 2021, as well as the most recent 10-year average of 470,000 total acres (198,000 forested acres). The majority of fire extent (both total and forested acres) occurred in eastern Washington; only 13,800 acres burned in western Washington, in contrast to 2022. Wildfires affected more acres of dry forest and cold forest than moist forest in eastern Washington and more cold forest than moist forest in western Washington. As in 2021 and 2022, burn severity was relatively evenly mixed among low, moderate, and high severity across all forest types.

Work of Wildfire in eastern Washington

In eastern Washington, the total number of wildfires in 2023 was high, but fire extent (30,200 forested acres) was substantially lower than the 10-year average due to weather and fuel conditions in addition to effective initial suppression efforts. Six large fires accounted for 92% of forested acres burned, highlighting the limited distribution of wildfire in eastern Washington. A tradeoff of relatively low fire years like 2022 and 2023 is that there were limited opportunities for beneficial fire effects on forest health. Fires reduced fuels and fire risk on 14,700 acres that burned at low and moderate severity in dry and moist forests, compared with 230,000 acres in 2021. Additionally, although only 15,400 acres of dry forest burned across eastern Washington in 2023, the areas that did burn experienced uncharacteristically severe impacts compared to historical fire regimes.

Work of Wildfire in western Washington

In western Washington, 2023 fire extent (13,800 total acres) was similar to the 10-year average (2014-2023) but substantially lower than the 54,300 acres that burned in 2022. Only 19% of the total acres burned at high severity, with 45% at moderate, 32% low, and 5% unknown severity. 83% of the total fire extent occurred in two fires: the Sourdough Fire in the North Cascades National Park and the Delabarre Fire in the Olympic National Park. These two fires predominantly burned in remote wilderness areas on steep terrain, but the Sourdough Fire also had major impacts on travel, facilities, and recreation along the Highway 20 corridor. Overall, high-severity fire affected 2,600 acres, including only 80 acres of old forest, initiating very little development of complex early-seral habitat. Additionally, low- and moderate-severity fire affected 2,700 acres of relatively low-elevation moist forests, corresponding to one third of the annual rate of variable density thinning in western Washington on US Forest Service and WA DNR land.

Management implications

These findings and other recent studies highlight the following management implications: (1) In eastern Washington, years with limited wildfire acres represent opportunities to accomplish positive work through prescribed fire and wildfire management operations. Assessing how to increase this beneficial fire is critical to achieving risk reduction and restoration goals; (2) Throughout western Washington, fire prevention and suppression remain important strategies. 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 continuing risk of large fires in eastern and western Washington underscores the importance of emergency preparedness, including evacuation planning for communities, home hardening and defensible space treatments, utility infrastructure management, and establishment of potential control lines along key roads and other features.

In addition to these key results and implications, the 2023 wildfire season demonstrated multiple lessons for ongoing and future work. Given recent trends and climate projections, wildfire will continue to be a major disturbance agent shaping forest health and landscape resilience. Evaluating the positive and negative effects of wildfires will become increasingly important for conservation planning and adaptive management.

INTRODUCTION

Across western North America, the need for large-scalem, intentional stewardship 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 and fuel reduction treatments, wildland fires and fire management are increasingly recognized as both challenges and solutions for landscape restoration and climate adaptation (National Cohesive Wildland Fire Strategy, U.S. Forest Service Wildfire Crisis Strategy). Indeed, in addition to the detrimental social, economic, and environmental impacts of wildfires, fires often have beneficial effects – such as reduced tree densities and surface fuel loadings – that decrease risks from and increase resilience to future wildfires and other disturbances (Fettig et al. 2019, Cansler et al. 2022, Taylor et al. 2022, Laughlin et al. 2023a). 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 partners are thus continuing to develop methods to integrate this positive "work" of wildfire into landscape restoration efforts while mitigating negative fire impacts (Dunn et al. 2020, 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 (20-Year Plan) to accelerate landscape-scale wildfire risk reduction, restoration, and climate adaptation efforts across all lands. Over the ensuing 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. Assessing the beneficial and negative effects of wildfires on landscape resilience and wildfire risk reduction objectives is a critical component of these efforts.

This report presents results of the 2023 DNR Work of Wildfire Rapid Assessment, which is the next annual installment following similar reports on the 2021 and 2022 fire seasons. The goal of this effort was to develop a rapid, data-driven evaluation of the effects of the 2023 wildfire season across eastern and western Washington. 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 ongoing assessments and future fire seasons.

The Work of Wildfire 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). These efforts complement parallel work evaluating fire effects and the utility of treatments for multiple objectives (**Appendix A**). Below, we present methods and results covering all of Washington, with subsections for eastern and western Washington.

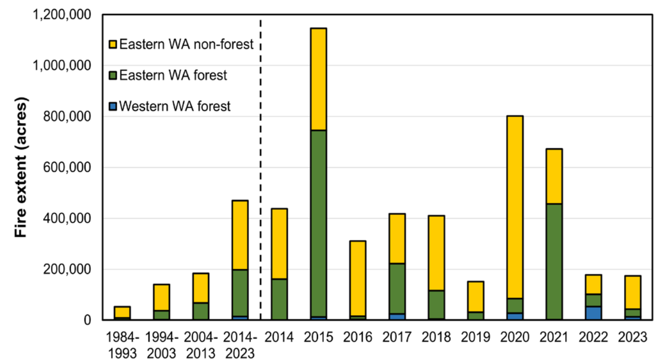

Figure 1. Total fire extent (acres) across Washington State from 1984 to 2023 by decadal average and individual year (2014-2023; bars to the right of the dashed line). Fire perimeters are compiled by the WA DNR Wildland Fire Management Division. 2015, 2020, and 2021 have been the largest fire years to date.

In 2023, total fire extent was similar to 2022 but far less than in 2021 (**Figures 1 and 2**). Despite the relatively low amount of fire in forested areas, there were substantial effects on social, economic, and ecological values, particularly in Spokane County. As in 2022, the socio-economic impacts of the 2023 fires were in many ways more significant than the ecological impacts. Smoke from within and outside of Washington affected communities statewide, causing health impacts and disrupting livelihoods and outdoor activities. Additionally, structure losses, evacuations, and road closures impacted communities, especially in the Columbia Gorge and Spokane County. Across the state, fire events larger than 100 acres affected 174,300 total acres and 44,000 forested acres (**Figure 1, Table 1**). Importantly, the total area burned in 2023 is just one component of wildfire impacts, and the 2023 fire events enable researchers and managers to continue elucidating fire effects and outcomes across a range of forest types and management objectives.

Table 1. 2023 wildfire extent and severity by forest and non-forest vegetation types. Estimates are preliminary and will change due to delayed tree mortality and other factors. Severity is not directly applicable to the non-forest class. Unknown severity is due to unavailable imagery, and these areas will be reassessed in the fall of 2024.

Vegetation type	High	Moderate	Low	Unknown	Total
Eastern WA	7,650	14,822	6,695	1,065	160,472
Dry	3,124	8,424	3,462	354	15,363
Moist	690	1,734	1,105	172	3,700
Cold	3,836	4,664	2,128	539	11,167
Forest subtotal	7,650	14,822	6,695	1,065	30,231
Non-forest	na	na	na	na	130,241
Western WA	2,568	6,137	4,390	635	13,828
Moist	376	1,234	1,482	129	3,221
Cold	2,193	4,902	2,908	506	10,509
Forest subtotal	2,568	6,137	4,390	635	13,730
Non-forest	na	na	na	na	98
Forest total (WA)	10,218	20,959	11,085	1,700	43,961
Grand total (WA)	10,218	20,959	11,085	1,700	174,300

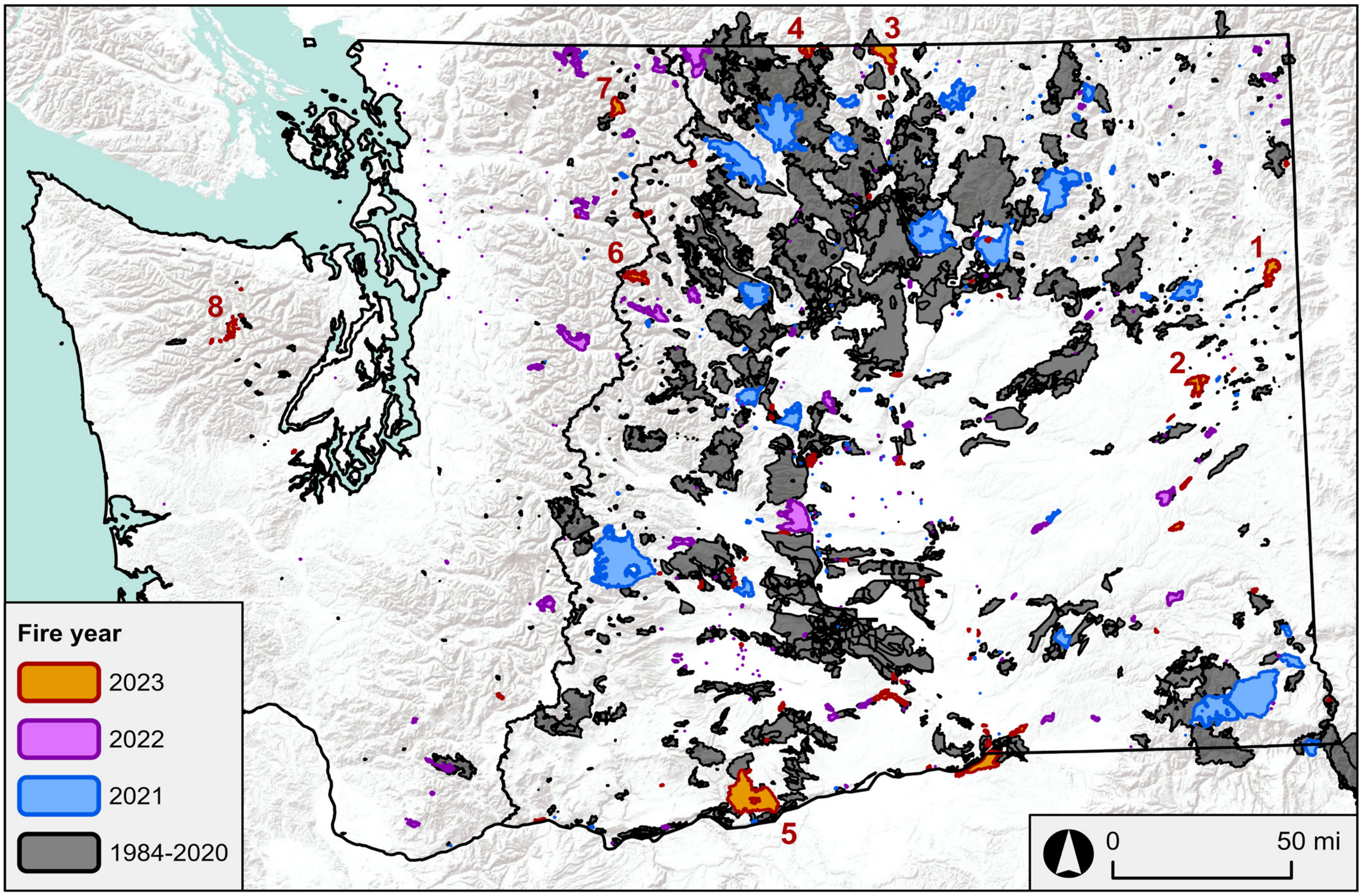

Figure 2. Recent fire patterns across Washington State from 1984 to 2022. Fire perimeters are compiled by the WA DNR Wildfire Division. The vast majority of fire extent has occurred in eastern Washington, delineated by the crest of the Cascade Range (black line). Red numbers indicate individual large fires highlighted in this report (**Figures 4-7, 10**): 1: Oregon; 2. Gray; 3. Eagle Bluff; 4. Crater Creek; 5. Newell Road; 6. Airplane Lake; 7. Sourdough; 8. Delabarre. 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, which focuses on eastern Washington and describes the ecological and social basis for landscape-level treatments to reduce wildfire risk and restore resilient, climate-adapted conditions. This 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 wildfires (Fule 2008).

In 2022, we advanced a broader framework 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 fire regime predominated by relatively infrequent (200-400+ years), high-severity fire. Westside fires are rarely limited by fuels and are primarily driven by weather (Halofsky et al. 2018), particularly when low fuel moistures combine with fire ignitions and strong east winds (Cramer 1957, Reilly et al. 2022). When these conditions aligned historically, large, 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 fire effects 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 in western Washington 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 fire stewardship 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 more frequent than previously hypothesized in the western Cascades (Andrew Merschel, pers.

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-, and high-severity fire in different forest types relative to historical ranges, focusing on high severity in dry and moist forests.	Proportion of low-, moderate-, and 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.

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

In western Washington, low- and moderate-severity fire effects have shorter-lived effects on reducing future fire intensity than in eastern Washington (Halofsky et al. 2018). This is due to lower frequency of fire, rapid regrowth of fuels, and the prevalence of large patches of wind-driven fire. In fact, reburns have occurred after many of 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). 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 for western Washington (**Table 2**). While the Work of Wildfire metrics in eastern Washington focus on burn severity variation relative to historical ranges in 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 there is substantial variation associated with site productivity, management history, and disturbance history.

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 (See **Appendix B** for detailed methods). This approach is similar to the RAVG program (https://burnseverity.cr.usgs.gov/ravg/). **Note that our burn severity maps are preliminary, are not field validated, 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 to use initial severity maps, although we will continue to evaluate severity patterns using post-fire imagery from 2024. Finally, all numbers in the report text have been rounded to the nearest 100 (e.g., 1,215 changes to 1,200) to aid in comparisons and because values may shift due to uncertainties in rapid burn severity maps. Values in the figures and tables have not been rounded.

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 class:

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+ 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.

2023 STATEWIDE SUMMARY ACROSS WASHINGTON

Across Washington, fire extent was relatively low compared to recent record-breaking years, including 2015 and 2021. May and June were dry, setting the stage for a long fire season, but lightning storms in July and August were generally accompanied by substantial rainfall (WA DNR Wildfire Report). Across the state, fire events larger than 100 acres affected 174,300 total acres, very similar to the 178,000 total acres that burned in 2022 (**Figure 1, Table 1**). However, 2023 fires burned only 44,000 forested acres, well below the 10-year average for 2014-2023 (**Figure 1**). The majority of fire extent (both total and forested acres) occurred in eastern Washington; only 13,800 forested acres burning in western Washington, in contrast to 2022, where over half of forested acres (53,600) occurred in western Washington (**Figure 1**).

Fire events were scattered throughout both eastern and western Washington (**Figure 2**). Several important fire events highlighted in this report occurred in remote settings in wilderness areas or national parks (Crater Creek, Airplane Lake, Sourdough, Delabarre; **Figure 2**). Multiple large fires burned across the US/Canada border (Eagle Bluff, Crater Creek) as well as in the Columbia Gorge (Tunnel 5, Newell Road). In Spokane County, the Gray Fire and Oregon Fire had devastating impacts on numerous communities. Surprisingly, there were no fire events larger than 100 acres in the Blue Mountains (**Figure 2**).

In terms of forest types, fire affected more dry forest (15,400 acres) and cold forest (11,200 acres) than moist forest (3,700 acres) in eastern Washington and more cold forest (10,500 acres) than moist forest (3,200 acres) in western Washington (**Table 1**). As in 2021 and 2022, burn severity was relatively evenly mixed among low, moderate, and high severity across all forest types (**Table 1**). Moderate severity was the most common outcome across all forest types (at least 38% of forested acres; **Table 1**). In the following sections, this report presents detailed fire patterns and forest health effects for eastern and western Washington, including impacts across different land ownerships and for several large fire events.

2023 WORK OF WILDFIRE IN EASTERN WASHINGTON

Overview

There were 54 fires that burned 100 or more acres in eastern Washington during 2023 (**Figure 2**). Wildfire extent totaled approximately 160,500 acres, including 30,200 forested acres (**Table 1**). The majority of 2023 forested acres in eastern Washington burned on federal lands (13,500 acres; 45%) and on land belonging to small private landowners (12,650, 41%). The remaining 14% of forested acres burned on industrial lands (2,600 acres; 9%), DNR Trustlands (800 acres; 3%), and about 2% combined on Tribal, other State, or "Other" ownerships (**Table 3**).

While the overall number of wildfires in 2023 was high (WA DNR Wildfire Report), fire extent was substantially lower than the 10-year average due to favorable weather and fuel conditions in addition to effective initial suppression efforts (**Figure 1**). Washington had a relatively wet winter and early spring, followed by hotter and drier conditions in May and June. Although there

Table 3. 2023 eastern Washington wildfire extent and severity by potential vegetation type and ownership. The vegetation map is based on USDA Forest Service data 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 2023 fires affected economic objectives most directly in high-severity portions of DNR Trustlands, small private, and industrial lands (~3,400 acres). Burn severity could not be calculated for a small number of forested acres, which are excluded from the table.

Forest type	Burn severity	USFS	Other Federal	Tribal	DNR Trustlands	Other State	Small Private	Private Industrial	Unknown	Total
Dry	High	14	195	1	89	46	2,239	524	17	3124
	Low-Mod	148	668	252	634	234	8,543	1,233	174	11,886
Moist	High	167	0	0	6	0	278	240	0	690
	Low-Mod	1123	0	2	67	0	1,051	541	54	2,839
Cold	High	3828	0	0	0	0	3	6	0	3,836
	Low-Mod	6743	3	0	0	27	6	13	0	6,792
Total unknown	na	854	227	69	307	30	1,463	96	1,626	4,673
Total forest	na	12,640	876	257	844	319	12,404	2,639	252	30,231
Nonforest	na	1,817	10,602	1,535	6,129	1,307	69,367	147	39,336	130,241
Total	na	14,457	11,478	1,793	6,972	1,626	81,771	2,787	39,589	160,472

were a number of lightning events in July and August, those storms were also accompanied by considerable rain.

The largest impacts on communities occurred in Spokane County during the Oregon and Gray Fires. These fires together burned more primary residences (366) than any other wildfires in recent history and are the subject of a Facilitated Learning Assessment (FLA) that will be published in 2024. The FLA describes how extreme fire weather and fire ignitions resulted in devastating impacts in both rural and urban settings.

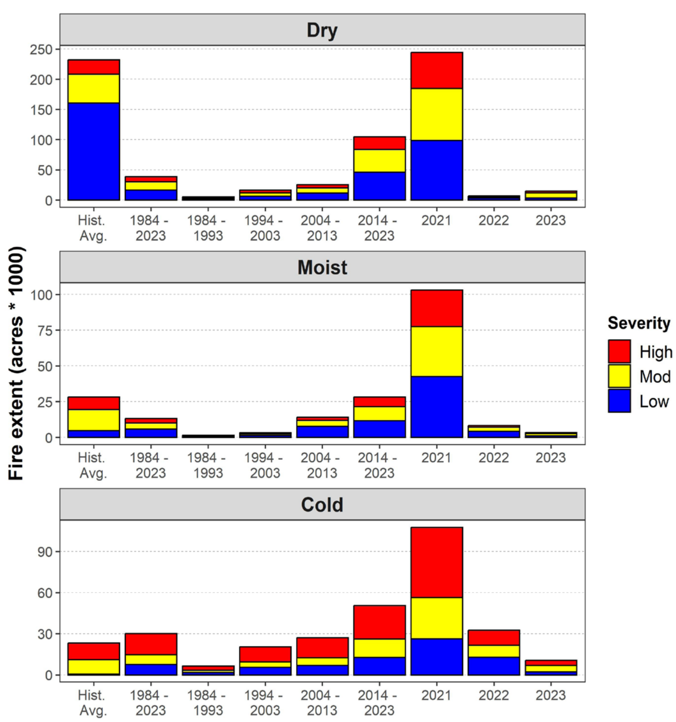

Figure 3. Estimated burn severity across forested areas of eastern Washington from 1984 to 2023 and historically by potential vegetation type (Haugo et al. 2019). Low-, moderate-, and high-severity classes correspond to 0-25%, 25-75%, and 75-100% tree basal area mortality, respectively. Burn severity 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.

About half of the forested area burned in eastern Washington in 2023 was in dry forests (15,400 acres). Moist forests accounted for about 12% (3,700 acres), and cold forests accounted for about 37% of the forested acres burned (11,200 acres) (**Figure 3, Table 1**). In addition, about 4% of forested acres (about 1,100 acres) were missing severity information due to poor pre- or post-fire imagery. Forest fire extents for each forest type were much lower than both the most recent 10-year averages (Dry: 106,000 acres; Moist: 28,400 acres; Cold: 49,900 acres) and historical averages (Dry: 232,000 acres; Moist; 28,600 acres; Cold: 23,200 acres) (**Figure 3**).

A tradeoff of relatively low fire extent in years like 2022 and 2023 is that there were limited acres with beneficial wildfire effects. Only 14,700 acres of low- and moderate-severity fire, which reduce surface fuels, tree densities, and associated fire risks, occurred in dry and moist forest in 2023, compared with 230,000 acres in 2021. The 2023 fire extent was similar to 2022, where about 12,000 acres burned at low or moderate severity in dry and moist forests. Based on historical fire regimes, dry and moist forests in eastern Washington need an estimated average of 227,700 acres of low- and moderate-severity fire 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. 2023). From 1986 to 2017, wildfires were the primary disturbance agent reducing restoration need in eastern Washington, but this reduction was offset by vegetation growth (Laughlin et al. 2023a).

In addition to the low wildfire extent, preliminary numbers suggest that relatively little prescribed fire was conducted in 2023 (WA DNR 2023). The 2023 burn season provided relatively short and limited weather windows in which land managers could achieve fuels management objectives between periods of high moisture closely followed by drying periods with higher fire risk. From 2017 to 2022, an annual average of 21,900 acres of prescribed-fire and piling and burning treatments were completed (WA DNR 2023).

Due to the limited fire extent across eastern Washington, the influence of forest health treatments on fire outcomes was not a major focus of this report. However, the Oregon and Gray Fires both overlapped previous treatments, including areas of prescribed burning and non-commercial thinning. The effects of those treatments on outcomes, especially in terms of fire operations, is addressed more in the Wildfire Interactions with Treatments & Suppression (WITS) survey, a project that is currently underway. See this article for more details. We are also actively working with partners to assess treatment effects on fire behavior and severity in more detail.

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

The 2023 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 detailed effects of individual fires. However, we present results for the six largest fires (fires with >1,000 forested acres; **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 Crater Creek Fire utilized the lightning ignition for resource benefit, to maximize firefighter safety, and reduce fire costs due to the remote location and difficult terrain. Also, while most of the Crater Creek Fire extent was in Canada, only the portion of the fire in Washington state was considered for these analyses (**Figure 6**). 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 providing 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 intentional 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 of particular concern because large areas of high-severity fire can set back landscape resilience and wildfire risk reduction objectives (Churchill et al. 2022).

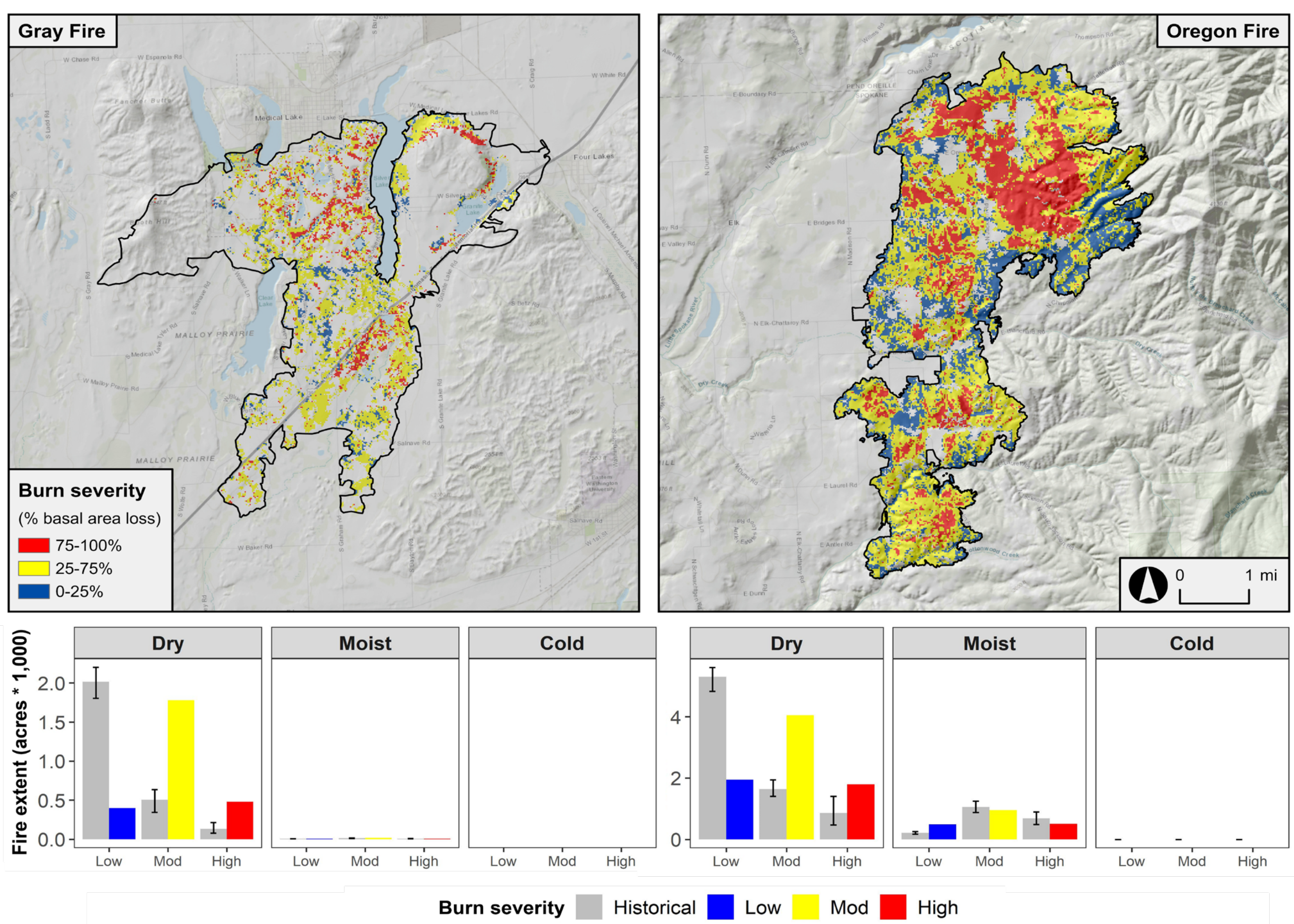

Figure 4. Burn severity of forested portions of the Gray Fire (left) and Oregon Fire (right) in eastern Washington, compared with estimated historical reference ranges (lower panels; Haugo et al. 2019). Fire effects in non-forested areas are not shown. Severity estimates are preliminary and will change due to delayed tree mortality and other factors.

While only 15,400 acres of dry forest burned across eastern Washington in 2023, the areas that did burn experienced uncharacteristically severe impacts relative to estimated historical ranges. In dry forests, burn severity was distributed among low-, moderate-, and high-severity fire (23%, 55%, 20%, respectively; **Table 1**), whereas historically most wildfire in these forests was low severity (69% on average) (**Figure 3**). Most of the dry forest burned in four fires: Oregon, Gray, Eagle Bluff, and Newell Road (**Table 4**), with the Oregon Fire accounting for nearly half of the dry forest burned. All four of these fires had much more moderate-severity fire in dry forests than historical ranges (**Figures 4 and 5**). The Oregon, Gray, and Eagle Bluff Fires also had more high-severity fire than expected based on historical distributions (**Figures 4 and 5**).

Cold forests had less severe wildfire than historical reference ranges; 19% of cold forests burned at low severity in 2023 compared to an annual average of 3% historically (**Figure 3, Table 1**). Conversely, 34% burned at high severity vs. an annual average of 52% historically (**Figure 3, Table 1**). Moist forests also burned with relatively low severity (30% low, 47% moderate, 19% high) relative to historical averages (17% low, 52% moderate, and 31% high), although the proportion of moderate-severity fire was similar to the historical average (**Figure 3, Table 1**).

The Oregon, Airplane Lake, and Crater Creek Fires accounted for the majority of burned acres in cold and moist forests (**Table 4**). The Airplane Lake Fire matched the historical range for moist forests, but it had more low- and moderate-severity fire in cold forests than expected based on historical ranges (**Figure 6**). The Crater Creek Fire had more low-severity fire than the historical reference range, but the moderate and high severity proportions were within the historical ranges (**Figure 6**). Both Airplane Lake and Crater Creek burned in relatively remote locations typical of cold forest types (**Figure 7**).

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). Low-severity fire consumes surface fuels and ladder fuels (i.e., 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). Moderate-severity fire also reduces 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

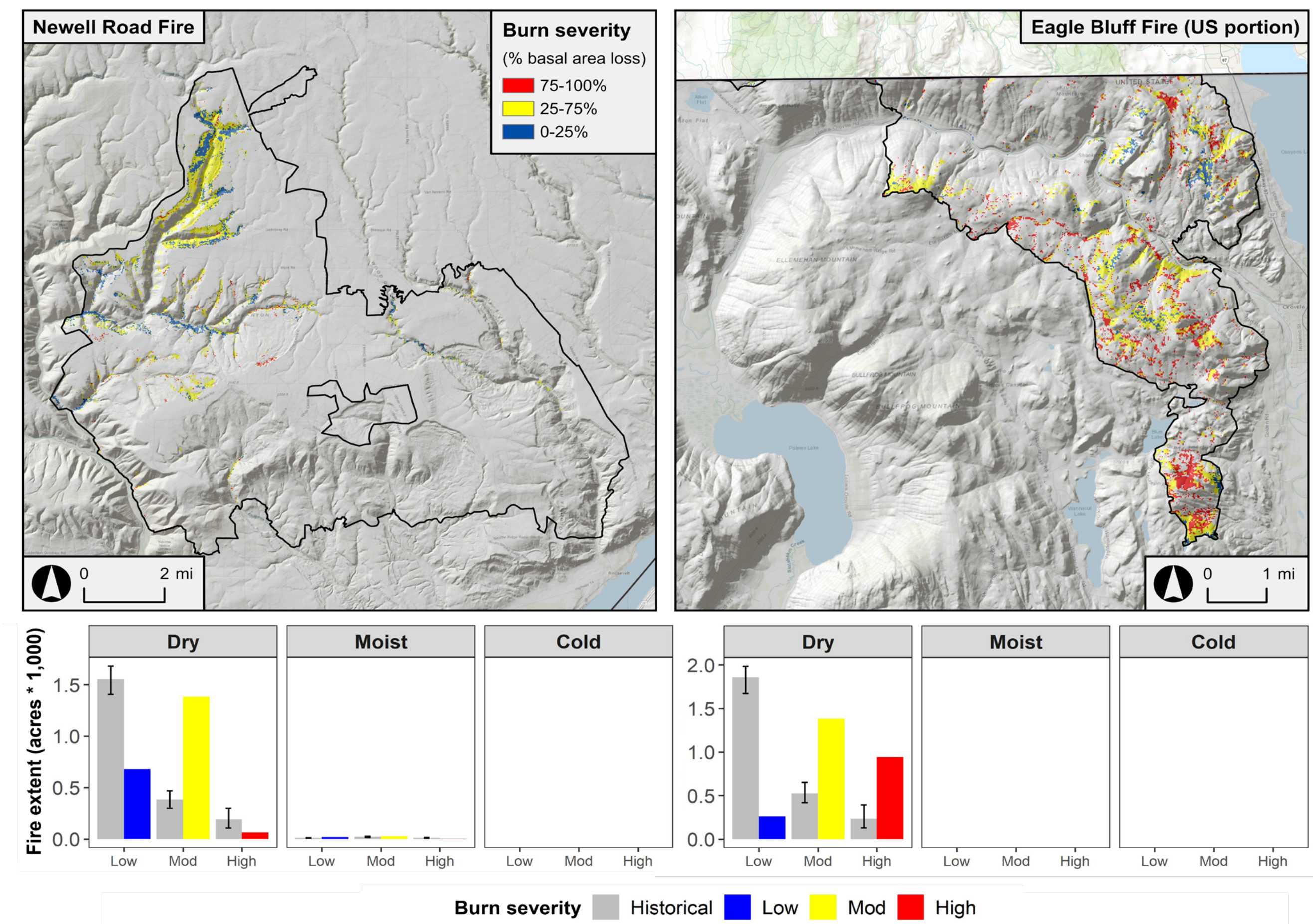

Figure 5. Burn severity of forested portions of the Newell Road Fire (left) and Eagle Bluff Fire (right) in eastern Washington, compared with estimated historical reference ranges (lower panels; Haugo et al. 2019). Fire effects in non-forested areas are not shown. Only the portion of the Eagle Bluff Fire in Washington was assessed for this report. Severity estimates are preliminary and will change due to delayed tree mortality and other factors.

Table 4. 2023 eastern Washington total acres, forested acres, and acres burned by forest type and burn severity for the six large fires that burned >1,000 acres of forest, plus all other fires combined and regional totals. The six large fires represent 68% of total acres and 92% of forested acres burned. ***Bold italic*** numbers indicate values above the historical reference range for that forest type-severity combination. Historical severity estimates are from Landfire as applied by Haugo et al. (2019). *The Crater Creek and Eagle Bluff Fires extended across the U.S. border into Canada, but only the portions in Washington were assessed for this report. See more individual fire metrics in **Table 5**.

Fire name	Total extent	Forested extent	Dry forest		Moist forest		Cold forest	
			High	Low-Mod	High	Low-Mod	High	Low-Mod
Oregon	10,827	9,208	***1,646***	5,696	482	1,356	9	19
Airplane Lake	6,959	6,066	1	20	154	689	510	***4,691***
Crater Creek*	5,134	4,440	0	0	0	0	3,113	1,326
Gray	10,065	2,571	***472***	2,077	4	17	0	0
Eagle Bluff*	16,445	2,526	***918***	1,608	0	0	0	0
Newell Road	60,552	2,147	64	2,040	0	42	0	0
All other fires	51,112	2,209	22	444	49	734	205	755
Total	161,094	29,167	3,124	11,886	690	2,839	3,836	6,792

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 2023, low- and moderate-severity wildfires burned approximately 14,700 acres in dry and moist forests of eastern Washington (**Table 1**), likely leading to forest health improvements. This total adds to the reported 571,000 cumulative footprint acres of forest management treatments in eastern WA from 2017 to 2022 (WA DNR 2024). Because of the relatively low fire extent in 2023, there was almost no area burned within the 20-Year Plan priority planning areas. These priority landscapes are areas where treatments and beneficial fire are especially needed due to high fire 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 type conversion to landscapes dominated by young forest, grassland, and shrubland (Cassell et al. 2019, Kemp et al. 2019). 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 absent in 2023. About half of the high-severity fire was in small (<100 acres) patches, and the remaining 1,200 acres were in medium patches (100-1,000 acres) (**Table 5**). Although the largest area of high-severity fire in dry forest occurred in the Oregon Fire (**Table 4**), with a higher proportion of high-severity fire than historical reference ranges, the patch sizes were relatively small (**Table 5**).

The vast majority of high-severity fire in cold forest occurred in the Crater Creek Fire (**Table 4**), including many

Table 5. 2023 eastern Washington work of wildfire metrics (in acres) for individual fires, all other firescbin combined, and regional totals: acres of dry-moist forests in large (>1,000 acres), medium (100-1,000 acres), and small (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 Crater Creek and Eagle Bluff Fires extended across the U.S. border into Canada, but only the portion of the fire in Washington was assessed for this report. See more individual fire metrics in **Table 4**.

Fire name	Forested extent	High-severity patches in Dry-Moist forest			Potential seed source limitation	Large tree severity			Riparian forest severity		
		Large	Medium	Small		High	Mod	Low	High	Mod	Low
Oregon	9,208	0	1,146	1,053	913	68	224	96	301	670	430
Airplane Lake	6,066	0	30	135	276	93	1,802	610	44	410	154
Crater Creek*	4,440	0	0	0	2,576	2	1	4	288	84	73
Gray	2,571	0	0	471	108	0	0	0	40	146	44
Eagle Bluff*	2,526	0	0	930	475	44	47	11	161	197	30
Newell Road	2,147	0	0	65	11	18	35	42	20	345	229
All other fires	2,209	0	14	45	218	36	171	159	14	43	46
Total	29,167	0	1,190	2,699	4,575	260	2,279	923	868	1,896	1,007

large, high-severity patches (**Figure 6**). 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 has exceeded historical fire regimes (Haugo et al. 2019, Donato et al. 2023), increasing the potential for conversion to young forest and non-forest vegetation types.

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 trailing edge forests vulnerable to drought and wildfire in the eastern Cascades of Washington (Meigs et al. 2023).

Overall, 4,600 acres that burned in 2023 in eastern Washington may experience tree seed source limitation (**Table 5**). However, only two of the largest six fires (Oregon and Crater Creek) had more than 500 acres beyond 500 feet from residual live trees.

Over half of the area with potential seed source limitation due to 2023 eastern Washington wildfires occurred within the Crater Creek Fire. As a result, an estimated 58% (2,600 acres) of the forested landscape within that fire footprint is now in high-severity patches over 500 feet from residual live trees. Like the 2022 Parks Fire, most of the Crater Creek Fire occurred in subalpine fir / lodgepole pine forests. Lodgepole pine may regenerate abundantly from non-serotinous and 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 260 acres with large trees burned at high severity in the 2023 fires, which is 8% of the total area burned

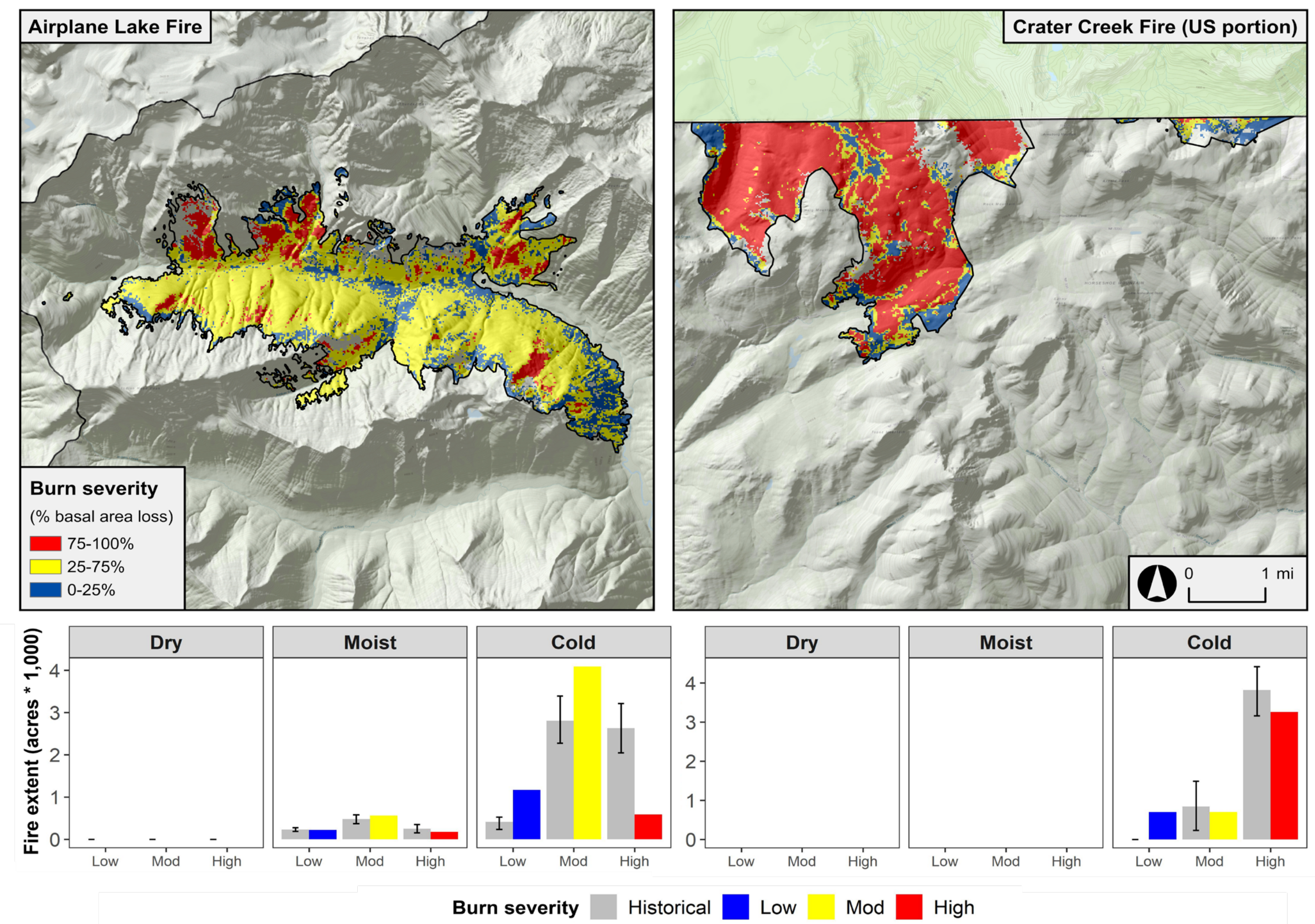

Figure 6. Burn severity of forested portions of the Airplane Lake Fire (left) and Crater Creek Fire (right) in eastern Washington, compared with estimated historical reference ranges (lower panels; Haugo et al. 2019). Fire effects in non-forested areas are not shown. Only the portion of the Crater Creek Fire in Washington was assessed for this report. Severity estimates are preliminary and will change due to delayed tree mortality and other factors.

Figure 7. Images of Airplane Lake Fire (left) and Crater Creek Fire (right). Both fires occurred in remote locations defined by cold forest types (**Figure 6**) and rugged terrain (top left). Various fire suppression strategies were deployed, including helicopter water drops (lower left), handline near high-elevation meadows (top left), and roadside fuelbreaks with hand chipping (lower right). Source for Airplane Lake photos: https://inciweb.wildfire.gov. Source for Crater Creek photos: Jon Grell (WA DNR).

containing large trees (**Table 5**). Across most fires, areas with large trees burned at moderate severity (66% of the total burned area with large trees). The high acreage burned at moderate severity was primarily due to the Airplane Lake Fire, which accounted for 1,800 of the approximately 2,300 acres of large trees burned at moderate severity. Addtional post-fire mortality of large trees will occur and may be substantial at some sites, especially locations with moisture stress (Busby et al. 2024).

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).

Wildfires affected approximately 3,800 acres of stream-adjacent forests in 2023. Burn severity in these areas was 27% low, 50% moderate, and 23% high (**Table 5**). This pattern of mostly moderate severity occurred across most large fires. Crater Creek exhibited 65% high severity in stream-adjacent forests, consistent with its overall severity proportions. 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.

2023 WORK OF WILDFIRE IN WESTERN WASHINGTON

Overview

In western Washington, total fire extent and the amount of high-severity fire were substantially lower in 2022 compared to 2023. Total fire extent, however, was similar to the 10-year average from 2014-2023 (**Figure 8**). 101 recorded fires burned 13,800 total acres (**Table 6**) compared with 54,300 acres in 2022. Two fires accounted for 83% of the acres burned (**Table 7**): the Sourdough Fire in the North Cascades National Park and the Delabarre Fire in the Olympic National Park (**Figure 2**). The other 99 fires were scattered across western Washington and were relatively small: 66 fires were under 5 acres, 24 fires were 5-100 acres, and 9 fires were 100-622 acres. Almost all of the burned acres occurred in national parks (88%) and national forests (11%) (**Table 6**). Only 235 acres of small-private and private industrial forestland burned. Approximately 75% of fire extent was in high-elevation cold forest types (e.g. Pacific silver fir, subalpine fir, mountain hemlock), while 25% burned in low- to mid-elevation Douglas-fir and western hemlock forest types.

Unlike in 2022, none of the fires experienced major spread events driven by east winds. Only 19% of the total acres burned at high-severity, with 45% at moderate-, 32% low-, and 5% unknown severity (**Table 1**). The proportion of high-severity fire was lower than in 2022 (19% vs. 27%) while the amount of moderate-severity was higher (45% vs. 22%). It is important to note that these severity estimates are based on rapid post-fire maps, are not field validated, and do not account for delayed mortality that can be significant (Busby et al. 2024), especially in cold forest types that lack fire-resistant Douglas-fir.

The social and economic impacts of the 2023 westside fires were far less than in 2022. The two major fires in 2023 (Sourdough and Delabarre) occurred at moderate- to high-elevation and burned primarily in remote wilderness areas. Evacuations were minimal, and smoke impacts were mild, except for localized effects near some of the fires. However, the Sourdough Fire had major impacts on travel, facilities, and recreation within the North Cascades National Park. The fire burned adjacent to Highway 20, which was closed numerous times. Closures included many campgrounds, trails, and popular recreation areas within the park, such as Diablo Lake. Facilities such as the North Cascades Institute and the Ross Lake Resort were evacuated and closed during most of the fire. Seattle City Light dams and electrical infrastructure were also threatened near Diablo Lake.

A complex of over 40 small, lightning-ignited fires on US Forest Service land in the upper Cowlitz Valley caused great concern due to the potential for an east wind event that could have threatened Packwood and other communities that were evacuated in 2022 during the Goat Rocks Fire. While these fires remained small, they were a reminder of the potential for large, wind-driven fires in western Washington that occur when an ignition or small fire combines with dry conditions and east winds (Donato et al. 2020). Finally, as almost all the fires occurred on federal land within wilderness areas, economic and social effects of fires related to timber production were not a factor in 2023.

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

The 2023 fires in western Washington had a range of beneficial and negative effects on forest health and landscape resilience. Here, we report on the metrics that quantify these effects (**Table 2**) and discuss their significance. **Appendix B** provides a detailed description of the methods used to evaluate these effects.

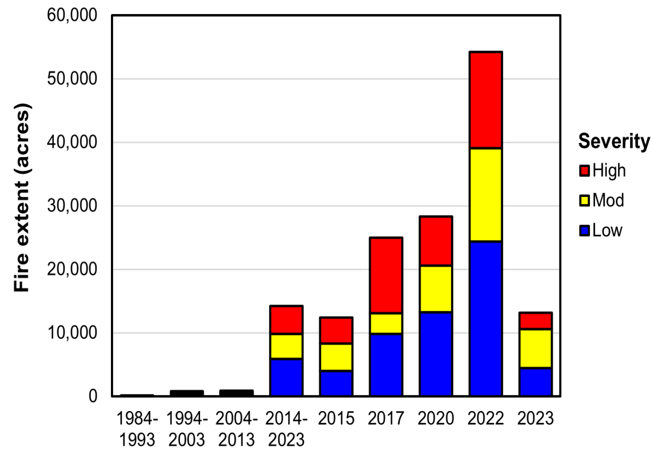

Figure 8. Western Washington fire extent and severity from 1984 to 2022. 10-year increments show annual average during that span. The five individual years (2015, 2017, 2020, 2022, and 2023) are the largest years in this period. Severity estimates are preliminary and will change due to delayed tree mortality and other factors. Fire perimeters are compiled by the DNR Wildland Fire Management Division.

1. Distribution of burn severity relative to forest structure stages

Within the 13,800-acre footprint of the 2023 fires, the most predominant forest structural stages were young (5,700 acres) and mature (3,800 acres) forest, followed by very young (2,600 acres) and old (1,700 acres) classes (**Figure 9**). Similar to 2022, burn severity was lower in mature and old forest structure classes. These results highlight that larger trees and older forests are often more fire resistant (Zald and Dunn 2018), particularly in topographically protected fire refugia (Meigs et al. 2020), but these effects are diminished during high fire-spread events (Reilly et al. 2022).

The 2023 fires shifted the distribution of structural stages within the fire footprint area. Young, mature, and old forests that burned at high severity have now shifted to the very young class (**Figure 9**). Most of this shift was from the 1,300 acres of young forest that burned at high severity, while only 600 acres of mature and 80 acres of old forest burned at high severity. The

Table 6. 2023 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, and these areas will be reassessed in the fall of 2024.

Forest type	Burn severity	National Park	USFS	Private Industrial	Small Private	Total
	High	269	12	78	16	376
Moist	Mod	1,117	42	49	26	1,234
	Low	1,378	89	7	8	1,482
	High	1,969	223	0	0	2,193
Cold	Mod	4,456	446	0	0	4,902
	Low	2,383	525	0	0	2,908
Total unknown	na	497	146	9	12	664
Total forest	na	12,050	1,479	142	60	13,730
Nonforest	na	51	13	19	15	98
Total	na	12,101	1,492	161	74	13,828

overall result is that very young and young forest each cover one-third of the post-fire landscape, with mature at 23% and old at 11% (**Figure 7**). Note, however, that structural stages are mapped based on tree height from LiDAR. Due to shorter tree heights at higher elevations, some of the areas we mapped as young and mature forest are likely in an older age class.

It is also important to keep in mind 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. The 2023 fires were small in size and so had a relatively small effect on structural stages within the larger surrounding landscape. However, both the Sourdough and Delabarre fires occurred in landscapes where increasing fire activity could have a substantial cumulative impact on the distribution and spatial pattern of forest structure. In particular, these fires have created many patches of early-seral plant communities, some of which may become meadows or shrublands for many decades. The recent trend of increasing fire in the North Cascades is projected to continue (Dye et al. 2024), which could drive a shift towards more area and larger patch sizes of early-seral plant communities, meadows, shrublands, and young forest. Mature and old forests may become increasingly restricted to valley bottoms, riparian areas on smaller streams, and other refugia (Meigs et al. 2020), especially as much of this landscape has steep slopes with relatively low-productivity soils.

2. Diversification of dense, mid-seral forest

The 2023 wildfires may lead to more diverse plant communities and complex forest structure in a significant portion of the 3,100 acres of mature and 4,200 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, non-stand-replacing fire can set back structural complexity and habitat values. 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 will continue to diversify structure over time in some areas. The extent to which westside fires accelerate vs. set back structural development will take time to fully evaluate and is the topic of ongoing research. Another factor is that roughly 75% of the low- and moderate-severity fire occurred in cold forest types (**Table 6**). The ecological effects of moderate-severity disturbances are not as well understood in westside, cold forests compared with lower-elevation forests. Secondary mortality is likely to be higher as well.

Although it is difficult to estimate how many acres of mid-seral forest (young and mature) will benefit from the 2023 fires in terms of diversification, the total for moist forest (2,500 acres) is roughly a third of the 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 western hemlock and Douglas-fir forests (Bailey and Tappeiner 1998, Carey 2003). In recent 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. The great majority of these thinned acres are in western hemlock / Douglas-fir forest types (moist forest).

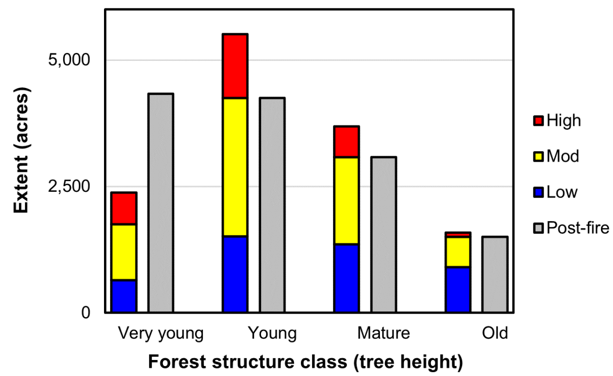

Figure 9. 2022 western Washington wildfire distribution of estimated pre-fire and post-fire structural stages. Remotely sensed, overstory tree height was used to classify four stages: very young: <40 feet; young: 40-90 feet; mature: 90-140 feet; and old growth >140 feet. Stacked bars display low-, moderate-, and high-severity extent for each pre-fire 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.

Table 7. 2023 western Washington total forested acres; extent and 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. See more individual fire metrics in **Table 8**.

Fire name	Total	Severity (acres)				Severity (%)				Largest patch
	extent (acres)	High	Mod	Low	Unknown	High	Mod	Low	Unknown	index (% HS)
Sourdough	7,346	1,797	3,508	1,833	208	24	48	25	3	23
Delabarre	4,169	394	1,756	1,786	234	9	42	43	6	50
All other fires	2,312	388	903	799	222	17	39	35	10	na
Total	13,828	2,579	6,167	4,418	664	19	45	32	5	na

3. Creation of early-seral habitat

Overall, high-severity fire affected 2,600 acres across western Washington in 2023, setting the stage for the development of early-seral habitat. Habitat type and quality will depend on forest type, pre-fire structure, site productivity, post-fire management, and other factors. High-severity fire in mature and old forest may lead to ~700 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). It 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 1,900 acres of structurally simple, early-seral habitat (**Table 8**). Although these areas lack the large snags, downed logs, and live large and old trees associated with early-seral habitat that originates from old-growth or mature forest, they may develop high plant diversity. In addition, mid-to-high-elevation areas may convert to shrublands or meadows with high habitat value (See discussion of the North Cascades above).

4. Delayed tree regeneration due to seed source limitation

An estimated 1,300 acres of the 2023 fires may experience limited or delayed tree regeneration in large, high-severity patches due to seed source limitation (**Table 8**). Similar to eastern Washington, we computed this metric by mapping higher-severity locations that are now greater than 500 feet from residual live trees in unburned, low-, or moderate-severity areas. However, tree regeneration is typically abundant in western Washington forest types, even in large, high-severity patches (Larson and Franklin 2005, Laughlin et al. 2023b). Thus, tree regeneration may be sufficient in many locations or delayed for several decades or more in others, depending on pre-fire conditions, landscape configuration of live and dead trees, and site productivity.

Most of the large patches of high-severity fire in 2022 occurred in moderate- to higher-elevation areas in the Sourdough Fire in the North Cascades (**Table 8, Figure 10**). A few of these patches are on steep slopes directly above Highway 20 and Gorge Lake. Delayed tree regeneration in high-severity patches may be especially concerning in this location because tree canopies and root systems reduce risk of landslides and debris flows. However, almost all of the large, high-severity patches are not directly above infrastructure or human structures. Because many of these patches are on steep slopes with thin soils that will limit tree establishment, they may convert to shrublands, meadows, or subalpine parkland with low tree density. Rapid tree regeneration is not necessarily desirable in these locations because these non-forest vegetation types have high habitat value, especially as they will have abundant snags and downed wood for several decades.

In addition, parts of the Delabarre Fire reburned the 2016 Godkin Fire and a small part of the 2017 Hayes Fire (**Figure 10**). Reburns can lead to much longer-term limitations in tree regeneration (Gray and Franklin 1997, Busby et al. 2020). While these reburn areas show moderate severity (**Figure 10**), inspection of aerial photographs from 2021 revealed high tree mortality across much of the Godkin Fire. Thus, this reburn will likely increase the potential for lasting meadow or shrubland vegetation types by killing existing tree regeneration and consuming a portion of the dead wood from the Godkin Fire.

5. Loss of old-growth forest

The 2023 fire season had minimal impacts on old-growth forests. Only 80 acres of old forest (sites with trees >140 feet tall) burned at high severity (**Table 8**). This amounts to 5% of the 1,700 acres of old forest that burned in 2023 (**Table 8**), and less than 1 % of the total forest area burned. An additional 600 acres of old growth burned at moderate severity (**Figure 9**), which may have negative or positive ecological effects, depending on pre-fire structure and composition and post-fire trajectories of live and dead vegetation.

6. Impacts to riparian and aquatic systems

An estimated 1,200 acres of stream-adjacent forests burned in 2023. Severity proportions were similar to severity across the total fire extent, with 11% burning at high severity, 52% at moderate, and 37% at low (**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 effects on large woody debris, sediment inputs via debris flows, productivity, shade and stream temperature, and associated fish habitat quality (Benda et al. 2004, Pettit and Naiman 2007). Fire events also influence snowpack and streamflow (Dickerson-Lange et al. 2021).

Table 8. 2023 western Washington work of wildfire metrics (in acres) for individual large fires (>1,000 acres), all other fires, and regional totals: potential seed source limitation (acres >500 feet from residual live trees); creation of early-seral habitat following high-severity fire (structurally complex in old / mature forest, structurally simple in young / 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. See more individual fire metrics in **Table 7**.

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
Sourdough	939	548	1,249	49	9.1	1,661	2,327	85	369	169
Delabarre	137	117	277	31	3.1	901	1,170	22	194	239
All other fires	186	22	366	1	0.4	518	749	20	55	36
Total	1,262	687	1,892	80	4.8	3,080	4,246	127	619	444

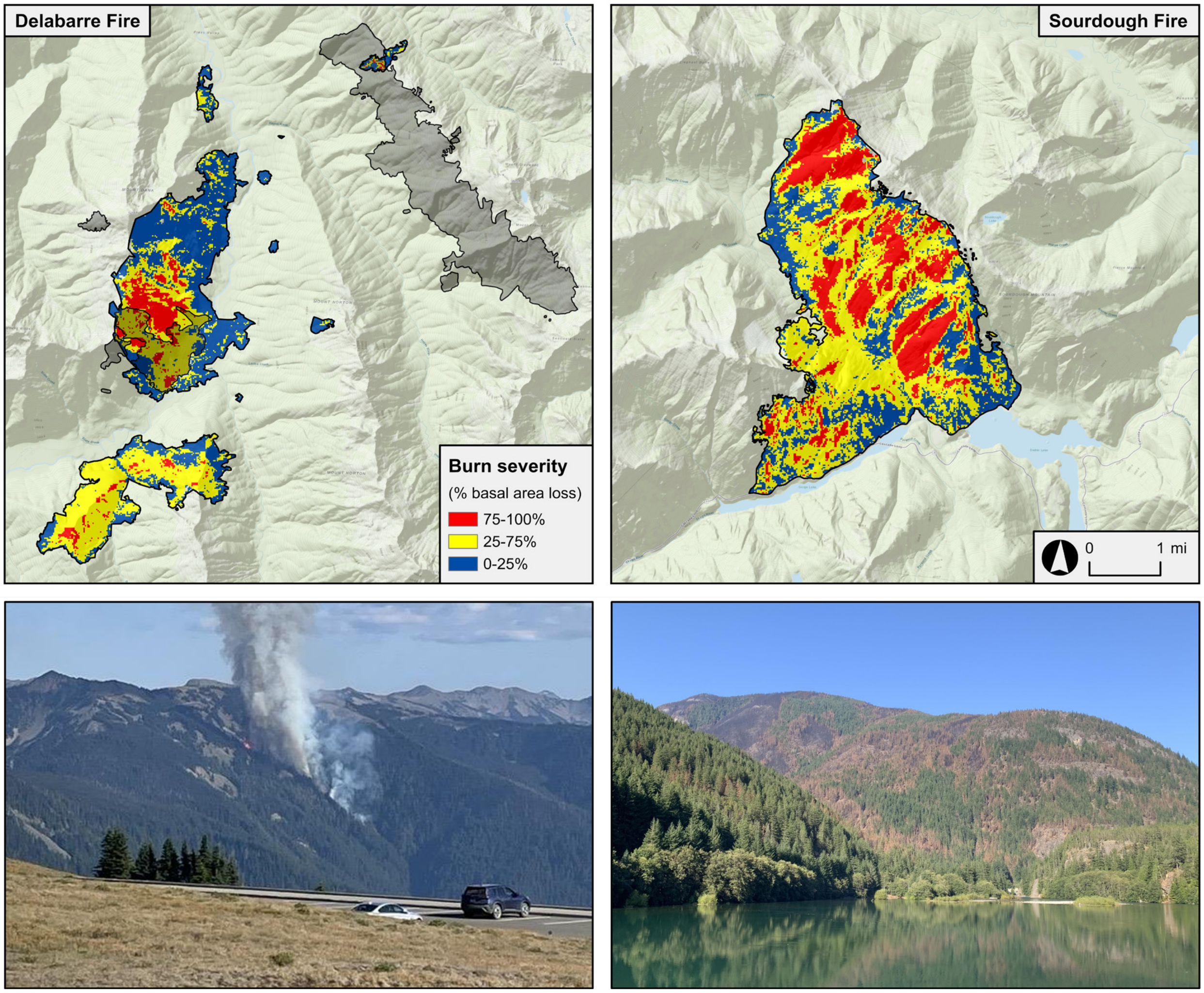

Figure 10. Burn severity maps and photos of the Delabarre Fire (left) and Sourdough Fire (right). The Delabarre Fire reburned most the 2016 Godkin Fire as well as a small portion of the 2016 Hayes Fire (upper left of Delabarre map). Severity estimates are preliminary and will change due to delayed tree mortality and other factors. Lower left photo shows the Eagle Point Fire from Hurricane Ridge (source: https://inciweb.wildfire.gov). Lower right photo shows portion of Sourdough Fire across Gorge Lake from Highway 20 (source: https://inciweb.wildfire.gov).

CONCLUSIONS AND KEY TAKEAWAYS

Despite relatively low fire extent, the 2023 wildfire season had substantial impacts on communities and ecosystems across Washington state. Wildfires affected air quality and community health, 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 instability, and debris flows. While these socio-economic impacts were extensive, the 2023 fires also had both negative and positive effects on landscape resilience and wildfire risk reduction objectives.

This report quantifies the work of wildfire in eastern and western Washington, which have distinct historical fire regimes and contemporary fire effects on forest health (**Table 2**). Across Washington, large fires (>100 acres) affected 174,300 total acres and 44,000 forested acres. These totals are relatively low compared to recent major fire years, including 2015 and 2021. The majority of fire extent (both total and forested acres) occurred in eastern Washington, with only 13,800 forested acres burning in western Washington, in contrast to 2022.

The 2023 Work of Wildfire assessment illustrates the following key findings:

Eastern Washington:

- The overall number of wildfires in 2023 was high, but fire extent (30,200 forested acres) was substantially lower than the 10-year average due to weather patterns and fuel conditions in addition to effective initial suppression efforts.
- Six large fires accounted for 92% of forested acres burned, highlighting the limited distribution of wildfire in eastern Washington.
- Fires reduced fuels and fire risk on 14,700 acres that burned at low and moderate severity in dry and moist forests. This estimate is far below the 2021 low-moderate severity total in these forest types (230,000 acres, which came with 124,000 acres of high-severity fire). The 2023 low-moderate severity total was also well below the historical annual average (227,700 acres), a critical target for what is needed to reduce surface fuel loads, tree densities, and associated fire risk to forests and communities.

- In contrast to 2021 and similar to 2022, there were no large patches of high-severity fire in dry or moist forests due primarily to the limited area burned in these forests.
- Additionally, although only 15,400 acres of dry forest burned across eastern Washington in 2023, the areas that did burn experienced uncharacteristically severe impacts compared to historical estimates.

Western Washington:

- In western Washington, 2023 fire extent (13,800 total acres) was close to the 10-year average (2014-2023) but was substantially lower than the 54,300 acres that burned in 2022.
- Only 19% of the total acres burned at high severity, with moderate-, low-, and unknown severity representing 45%, 32%, and 5%, respectively.
- 83% of the total fire extent occurred in two fires: the Sourdough Fire in the North Cascades National Park and the Delabarre Fire in the Olympic National Park. These two fires predominantly burned in remote wilderness areas on steep terrain in mid-to-high-elevation forests, but the Sourdough Fire also had major impacts on travel, facilities, and recreation along the Highway 20 corridor.
- Overall, high-severity fire affected 2,600 acres, including only 80 acres of old forest, initiating very little development of complex early-seral habitat. Additionally, low- and moderate-severity fire affected 2,700 acres of relatively low-elevation moist forests, corresponding to one third of the annual rate of variable density thinning in western Washington on US Forest Service and WA DNR land.

Based on these findings, the analysis conducted for this report, and conclusions from other recent studies, we highlight the following management implications:

- 2023 and 2022 represented a welcome respite from the large fire years that have challenged fire operations and communities in eastern Washington over the last decade. However, wildfires accomplished relatively little positive work in terms of reducing fuels and future wildfire risk. Vegetation growth and fuel accumulation continue to increase risk throughout eastern Washington.
- In eastern Washington, assessing how to maximize the amount of beneficial fire through prescribed fire and wildfire management operations, especially during years that have windows of favorable weather conditions such as 2023, is critical to achieving the goals of the DNR 20-Year Plan and the U.S. Forest Service 10-Year Wildfire Crisis Strategy. 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 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.
- Although landscape-scale fuels treatments are not likely to reduce fire spread or severity during major wind-driven fires in western Washington, fuel reduction treatments may be warranted in some forests, particularly near communities, infrastructure, and vulnerable habitats.
- The continuing risk of large fires in eastern and 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 findings and implications, the 2023 wildfire season provided insights for future assessments. Moving forward, we will continue collaborating with partners to interpret the effects of recent fire seasons while preparing for the future. We will also continue to refine methods for mapping burn severity and delayed tree mortality while improving forest health treatment databases to enable a more robust synthesis of how treatments influence fire behavior and effects, wildland fire operations, and subsequent fire risk and landscape resilience.

Wildfire activity is projected to increase across western North America and in Washington state (Dye et al. 2024). 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 potentially beneficial effects of wildfire will become increasingly important. Given recent warming trends and climate projections, 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 realistic way to treat forest landscapes fast enough - and maintain them over time - is by harnessing the beneficial work of wildfires in the appropriate places and under safe conditions, while suppressing fires that threaten resources and communities. Over time, restored landscapes will provide managers additional flexibility to manage wildfire to protect communities, achieve forest health objectives, and maintain fire-dependent ecosystems.

LIST OF APPENDICES

ACKNOWLEDGMENTS

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Box 2. Ongoing efforts to assess the Work of Wildfire

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. Based on input from a 2022 workshop (summarized in the 2022 report) 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 2023 to conduct this analysis, but we demonstrated spread patterns for the 2022 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. Results in a forthcoming paper show that thinning followed by prescribed burning reduced fire severity, even during high spread days. See King5 and NW Public Radio stories.
- Contributing to a Joint Fire Science Program project to expand the Schneider Springs Fire analysis to examine treatment-fire interactions across many fires. The project also includes a toolset to rapidly analyze treatment effectiveness and further improve methods to collect information on treatment use during wildfire operations.
- Advancing 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.
- Working with the USFS, Northwest Fire Science Consortium, and other partners to facilitate field-based workshops addressing research, management, and social challenges and opportunties to leverage the work of wildfire.

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Appendix A. Summary of complementary efforts related to the WA DNR Work of Wildfire Assessment (2023)

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	NIFC website
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 summaries from Wildland Fire 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	Field-based monitoring program	Home page
FIREMON (CBI/dNBR)	Interagency	Methods for remote sensing and field assessment (composite burn index)	CBI description
Northwest Fire Science Consortium	Interagency	Regional syntheses for applied fire science and management, collaborative decision support	Home page

Appendix B. Detailed methods and data for the WA DNR Work of Wildfire Assessment (2023)

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 January 2024 from the DNR Large Fires database (from the National Interagency Fire Center (https://ftp.wildfire.gov/)) and pre- and post-fire satellite imagery (details below). 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, are not field validated, 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.

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-8 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 Sentinel data for estimating 2023 severity because it produced more reasonable maps based on manual inspection of pre- and post-fire imagery.

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 dates may be used, but mid-October produced the most accurate results for our analysis for most of the fires. 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.

In 2023, we updated the methods to limit severity mapping to fires over 100 acres. This allowed us to manually inspect the burn severity maps for each fire and tune the pre- and post-fire imagery periods if necessary. While the default July and October imagery dates worked well for the majority of the 2023 fires, dates were adjusted for 10 of the fires (**Table B1**).

Although both RAVG and R6 burn severity maps are available externally for most large fires, the DNR Forest Health Science Team created separate maps using the R6 method in order to rapidly 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 use the R6 approach because of advantages in computational and staff time, and the need for consistent burn severity methods among individual fires.

There are several concerns that arise from using the R6 method that should be noted. The method tends to slightly overestimate burn severity in lower severity zones (see 2021 report 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. Offsets are values determined from adjacent unburned areas to account for year-to-year changes in vegetation spectral conditions (e.g., due to differences in climatic conditions or phenology). This 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 with this approach 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.

Table B1. Pre- and post-fire Sentinel-2 imagery dates for the 10 fires that did not use the default July and October imagery dates for 2023.

Fire name	NBR time frame	Date range
Airplane Lake	pre	06/15 - 07/06
	post	09/15 - 10/15
Blue Lake	pre	07/01 - 08/14
	post	09/05 - 09/30
Consalus	pre	06/01 - 06/27
	post	07/30 - 08/15
Crater Creek	pre	08/01 - 08/06
	post	08/30 - 09/15
Dome Peak	pre	07/01 - 07/28
	post	09/25 - 10/15
Gray	pre	08/01 - 08/17
	post	08/25 - 09/05
Kindy Creek	pre	08/01 - 08/15
	post	08/30 - 09/15
McEwan	pre	06/20 - 07/03
	post	07/15 - 07/30
Sourdough	pre	07/15 - 07/29
	post	10/01 - 10/15
Spencer Quartz	pre	08/01 - 08/24
	post	09/01 - 09/24

B. METRICS FOR EASTERN WASHINGTON

All metrics detailed below were assessed for the 10 largest fires (>1,000 forested acres) 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 B2**). 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 B2**. 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 two largest fires (>1,000 total acres) 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 data were 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 from 2022 report: acres burned and severity by burn period

To assess the relationships between spread rates and severity and to identify acres that burned on wind-driven "blow-up" days with high fire spread vs. low- and 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.

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Table B2. 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