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A spatial database of historical fire in westside forests of the Pacific Northwest

Running footer: Spatial Database of Historical Westside Fire

3 tables, 6 figures

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Abstract

Recent fire activity across forests west of the Cascade Crest in Oregon and Washington (the "westside") has increased interest in the region's historical fire regimes. Substantial spatial information exists describing the location, extent, and timing of historical fires in the region, but these records represent independent efforts at local-to-regional scales, with considerable variation in data resolution, methodologies, discoverability, and metadata. To address the need for a systematic dataset of historical westside fire, we compiled a spatial database of over 7,300 fire perimeters and burned areas covering 125,000 km^2, sourced from 25 datasets including historical forest inventories, cohort age studies, fire atlases, and aerial photo interpretations. We provide metadata, documentation, and guidelines for applying and interpreting the database, as well as three case studies illustrating possible applications and potential limitations. While the database documents extremely large and well-known fires such as the Tillamook Burn and Yacolt Burn, it also points to the historical importance of smaller fires and patches of stand-replacing fire on the westside. The case studies demonstrate 1) historical variability in stand-replacing patch sizes during wind-driven fire events, 2) resilience to early 20th century fire along the North Santiam River of Oregon, and 3) the role of repeated fire in early seral landscape diversity in the Coast Range. By considering the strengths and weaknesses of individual sources and using multi-proxy corroboration to reduce uncertainty, this publicly available database provides opportunities for new insights into the geographic variability of historical fire regimes on the westside.

Key Points

- We developed a spatial database of over 7,300 historical fire perimeters across western Oregon and Washington, available online at https://doi.org/10.5281/zenodo.19120166.
- Historical sources vary in spatial and temporal confidence, but can be used effectively by considering those limitations and finding corroboration in complementary data like aerial photography and field measurements.
- Case studies demonstrate the resilience of westside forests to stand-replacing fires that created early seral conditions across a wide range of spatial scales.

Keywords: Spatial dataset; Fire regimes; Westside fire; Early seral forests

Introduction

Fire has been an important driver of stand and landscape dynamics in temperate forests west of the Cascade Crest in Oregon and Washington ("the westside") for millennia (Agee 1993, Walsh et al. 2015, Reilly et al. 2021). These forests cover a broad range of climatic and biophysical gradients with heterogeneous fire activity, from typically infrequent, high-severity fire regimes in northern, coastal, and higher elevation forests (Agee 1993), to frequent and moderately frequent mixed-severity fire in lower elevation forests in the southern Cascades (Morrison and Swanson 1990, Weisberg and Swanson 2003, Tepley et al. 2013, Merschel et al. 2024). Cultural burning by Indigenous peoples prior to European colonization (Boyd 1999, Robbins 1999) and lightning ignitions near the Cascade Crest and in the southern Oregon Cascades have also supported frequent, low-severity fire regimes in some westside forests (Boyd 2022, Johnston et al. 2023). Throughout the region, infrequent very large fires (>40,000 hectares) driven by dry downslope east winds across the Cascade Crest have created extensive stand-replacing patches (Agee 1993, Reilly et al. 2022). Recent increases in fire activity on the westside, including multiple very large high-severity fires (e.g., the 2020 Labor Day fires) have prompted widespread interest in historical fire activity in this region. Early 20th century records of historical fire perimeters and their effects on forest conditions have proven useful for understanding historical fire regimes in dry forests of the region (e.g., Hagmann et al. 2019), but efforts to compile regional datasets of historical fire have been limited in westside forests.

Prior to 1984 when reliable satellite imagery enabled systematic mapping of fire activity across the United States (Eidenshink et al., 2007), fire perimeters on the westside were mapped as independent efforts at local-to-regional scales, with inconsistent objectives, constraints, and methodologies. These historical datasets include fire atlases and forest inventories from the late

1800s and early 1900s, as well as retrospective studies based on photo interpretation and field measurements of fire effects and post-fire tree cohort establishment. While historical datasets have inherent limitations and biases, often focusing on large, high-severity burns that impacted Euro-American settlers, federally-managed lands, and commercially valuable timber, they provide a critical source of information on historical fire regimes of the westside, in the absence of cross-dated dendroecological studies that are more widely available in drier eastside forests (Merschel et al. 2021). Previous efforts to compile historical fire records across the United States (Wildland Fire Decision Support System 2018, Welty and Jeffries 2022) and western North America (Welch 2021) provide valuable information at broad scales, but may not include regionally-specific datasets and indirect proxies for fire history that are critical for capturing the complexity of westside fire regimes.

To address the need for a comprehensive spatial fire history dataset for the westside, we compiled and categorized historical fire perimeters and burned areas from a wide variety of sources across western Oregon and Washington prior to 1984, providing a spatial database for reference in science and management (available at https://doi.org/10.5281/zenodo.19120166). These sources include both direct and indirect proxies for fire history with varying levels of spatial and temporal confidence, including fire atlases, aerial photo interpretations, cohort age studies, and forest inventories. To facilitate analysis, we provide documentation, guidelines, and recommended applications for different sources. We also present three case studies as practical examples demonstrating the utility and limitations of the database by exploring: 1) fire size class distributions and fire weather during the Great Fires of 1910, 2) post-fire landscape recovery from early 20th century fire along the North Santiam River, Oregon that burned in the 2020 Labor Day fires, and 3) fire history of an early seral landscape in the Oregon Coast Range.

Methods

Study Area and Data Collection

The westside encompasses three major forested ecoregions west of the Cascade Crest: the Olympic Peninsula in western Washington, the Coast Range in western Oregon, and the Western Cascades. The region is characterized by a Mediterranean climate, with most precipitation occurring during winter, including substantial snow at higher elevations, and warm, dry summers, especially in inland areas and in southern Oregon. Moist, temperate rainforests dominate the majority of the region, including Douglas-fir and western hemlock at lower elevations, and Pacific silver fir and mountain hemlock at higher elevations (Franklin and Dyrness 1973). In drier portions of the region, grand fir and Douglas-fir are dominant. We constrained analysis to the three ecoregions that define the westside, but chose to include fire perimeters in the drier Oregon Klamath Mountains within the database, as existing datasets often span ecoregion boundaries.

We began compiling spatial datasets of historical fire from previous localized efforts and Forest Service General Technical Reports (e.g., Henderson et al. 1989, Harrington 2003). Further datasets from across the westside were obtained from individuals and agencies following outreach efforts and presentations of our preliminary results (e.g., Welch 2021, Welty and Jeffries 2022). Other sources were discovered and acquired through public GIS portals and correspondence with personnel from public agencies (e.g., Wildland Fire Decision Support System 2018, Bureau of Land Management 2020). Finally, perimeter maps from published literature and paper archives (e.g., Cox 1902, Juday 1976, Dickman 1984) were scanned, georeferenced, and digitized with QGIS software (QGIS Development Team 2024) by matching ground-control points to mapped landmarks such as roads, lakes, and public land survey system boundaries, and applying thin plate spline transformations.

Fire perimeters from all source datasets were projected into a common coordinate reference system (UTM Zone 10N). Multi-part polygons representing distinct burned areas were separated, and all perimeters were filtered based on spatial intersection with the westside, defined by the forested EPA Level III Ecoregions west of the Cascade Crest (available online at https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states; Figure 1A).

Classification and Evaluation of Data Sources

The sources compiled into this database represent a wide range of mapping methods and sampling strategies, with corresponding differences in spatiotemporal accuracy and appropriate applications. To clarify these differences and facilitate queries to meet individual project requirements, we categorized perimeters into five methodological source types—fire atlas, photo interpretation, cohort age, forest condition map, and compiled—and assigned ranges of spatial and temporal confidence (Table 1) by reviewing publications, corresponding with source authors and other fire ecologists, and evaluating agreement between sources and other proxy datasets.

Fire perimeters that were mapped in response to specific events, often shortly after fire to document and quantify timber losses, were grouped into the fire atlas category. The relatively fine scale of these maps contributes to a moderate-to-high spatial confidence, depending on the original mapping method, with the caveats that 1) surveyors may have attributed to single fires the effects of multiple fires accumulated over decades, especially in the late 1800s and early 1900s; and 2) lower-severity fire effects may have been omitted as they are harder to distinguish and have less commercial impact than high-severity, stand-replacing fire. Temporal confidence for fire atlases is high at the perimeter-level, with exact years ostensibly known in every case, but the inclusion of earlier fires within perimeters may introduce uncertainty into the last fire year at a given location.

Photo-interpreted perimeters were mapped by visually delineating fire effects, such as deforested patches and snags, from aerial photography acquired within a few years to a few decades of fire. Spatial confidence for these perimeters is relatively high due to the fine resolution and positional accuracy of the source data, but likely decreases with the delay between fire and photo acquisition as regrowth masks lower-severity fire effects. Temporal confidence varies, with some perimeters being mapped retrospectively from known events with recorded years (e.g., Gifford Pinchot National Forest, 2016), and others being mapped opportunistically with fire years estimated from the level of post-fire recovery (e.g., Anderson et al., 2001). Where available, the year of photo acquisition was included in the comments field for each perimeter to provide additional context.

Fire perimeters that were mapped from second-order fire effects—namely, the establishment of new even-aged cohorts following stand-replacing fire—were grouped into the cohort age group. These sources delineate fire boundaries around contiguous patches of forest structure identified through aerial photo interpretation or by interpolation between plot locations, and assign fire years based on tree ages estimated through allometric equations or ring-counting on minimally-prepared stumps and cores (i.e., not cross-dated). Spatial confidence for these sources is limited by the difficulty of accurately identifying even-aged forest patches from aerial photography, the omission of non-stand-replacing fire effects, and the inability to separate multiple cohorts establishing after a series of small fires from a single cohort following a large fire. Temporal confidence is similarly limited by the imprecise nature of estimating cohort ages without cross-dating, and the variability in timing between fire and cohort establishment.

Unlike the other perimeter types that ostensibly represent individual fires, forest condition maps provide a snapshot of burned areas at the time of data collection. These surveys were conducted systematically across wide regions, reducing sampling bias and generating spatially consistent data not available from the other source types. Spatial confidence of these perimeters varies based on the original mapping methods, which were a combination of field reconnaissance and aerial photo interpretation (Harrington 2003), and the quality of georeferencing when paper maps were digitized. Temporal confidence in fire years associated with perimeters are low, as they represent only the survey year in which the perimeter was mapped in a burned state. Perimeters may have burned decades prior to mapping and likely include the effects of multiple overlapping fires while omitting lower severity fire effects that were concealed by regrowth.

In many cases, adequate metadata were not available to classify a perimeter into the categories above, so a fifth category was reserved for perimeters compiled from unidentified sources with unknown methods. These sources likely contain a mixture of accurately mapped and roughly estimated perimeters. Without the metadata necessary to separate them, we generally assume a low confidence level in the absence of corroborating evidence or additional documentation.

Generating Consistent Metadata and Geometry

Given the different constraints and objectives under which each source dataset was originally created, available metadata varied widely. To harmonize these datasets into a single consistent database, we determined a set of eight metadata fields that could be identified from every source and would provide relevant information to guide users and allow effective querying (database field names in parentheses): a unique perimeter identifier (uuid), fire name (name), fire year (year), perimeter area (hectares), source author (source_author), source type (source_type), source extent (source_extent), spatial confidence (spatial_confidence), temporal confidence (temporal_confidence), and additional comments (comments).

Each perimeter was assigned a universally unique identifier using the uuid module in Python 3.10. Fire names and years were cross-walked from each source dataset after filtering out placeholder values like “Unnamed” or “Unknown”. Fires without recorded names were retained in the database, while those with unknown or missing years—only five small perimeters that were not duplicated elsewhere in the database—were removed to avoid potential confusion from introducing a nullable year field. Next, the name of the original source author was added to each perimeter to help track provenance and provide additional context regarding confidence and mapping methods. Based on the source author and other available metadata, fields were added to describe the source type, approximate geographic extent, and spatial and temporal confidence. Confidence levels were broadly assigned by source type (Table 1), then refined for each source based on published documentation and our own analysis, e.g., lowering the spatial confidence for a source where perimeters were consistently misaligned with subsequent forest condition maps. The confidence levels of individual perimeters were further adjusted based on available metadata, e.g., a perimeter that was marked as an “estimated fire year” was assigned a lower temporal confidence than other perimeters from the same source. Finally, any additional relevant information from original source datasets such as archival record locations, additional sources of uncertainty, and mapping method details were included in a comment field for each perimeter.

Further processing was applied to generate consistent and usable spatial geometry data. Some datasets included many disconnected and distant perimeters within single records. To enable effective spatial queries, all perimeters were first split into single-part polygons, with each part retaining identical metadata. Next, nearby polygons within a five-kilometer distance that shared a common name, year, and source were re-merged into multi-part polygons that ostensibly represent single fire events. Nearby unnamed polygons were left distinct, since they may have occurred independently in the same year.

Identifying and Removing Duplicate Perimeters

Because this dataset was compiled from many independently created sources, duplicate data was inevitably included. In the case where a spatially identical fire perimeter was included from multiple different sources, duplicates were automatically identified by comparing recorded fire years and centroid locations. From each set of duplicates, a single perimeter was chosen by prioritizing sources with more complete metadata and higher confidence source types. In rare cases, spatially identical perimeters with different fire years were identified manually, and a final perimeter was chosen based on corroborating historical records, where available.

In other cases, single fire events were duplicated with conflicting spatial information from multiple sources, such as perimeters that were offset by kilometers or had substantially different shapes (e.g., Figure 2). These duplicates were identified manually by locating overlapping perimeters within each year, and final perimeters were chosen by comparing 1) metadata completeness, 2) metadata relevance, such as a contemporary map created immediately after an event versus a compiled collection, 3) corroboration with other sources such as historical records and aerial photographs, and 4) consistency with other spatial information such topography, rivers, and lakes.

To maintain their value as systematic inventories, burned areas in forest condition maps that appeared as fire perimeters in preceding years were not considered as duplicates. For example, some burned areas in the 1900 forest condition map likely originated with the 1868 Coos Fire, but both sets of perimeters were included because each provided unique and valuable information.

Case Study 1: The Great Fires of 1910

In late August 1910, a series of large wind-driven fires burned across the northwestern United States in an event known as the Great Fires of 1910 (Diaz and Swetnam 2013). While the largest of these fires in northern Idaho and Montana are well-documented, we found no comprehensive records of the event on the westside in existing spatial fire databases. During the course of data collection, we acquired and digitized a contemporary report that mapped extensive fires across the westside associated with the 1910 fires (Plummer 1912; Figure 3). The report does not detail the original mapping approach, which likely mirrored other contemporary burned area surveys that were conducted from horseback and high vantage points (Thompson and Johnson 1900, Gannett 1902, Plummer et al. 1902), but does reveal that mapping was limited to federal lands and excludes some fires as “a graphic record of [all fires], on the scale used, would be impossible.”

As an exploratory case study, we compared fire size distributions and contemporary weather between the 1910 fires and a sample of large, well-documented westside fire events including the 1902 Yacolt Burn, the 1933 Tillamook Burn, and the 2020 Beachie Creek fire. Large fires without recorded dates, like the Yaquina and Nestucca, were not included in the analysis. To assess spatial agreement, we overlaid the perimeters with subsequent historical maps of burned areas (Elliott and Rowland 1914, Harrington 2003, Bureau of Land Management 2020; Figure 4). Gridded weather data contemporary to each fire event was acquired from the NOAA-CIRES-DOE 20th Century Reanalysis dataset (20CRv3; Compo et al., 2011; available online at https://psl.noaa.gov) for pre-2016 fires and NCEP North American Regional Reanalysis dataset (Mesinger et al. 2006) for recent fires. We calculated maximum three-hour surface vapor pressure deficit and wind velocity at reported fire locations over a three-day window surrounding each event and plotted measurements between fires to assess relative differences in fire weather. Finally, we examined the proportion of area burned by size class bins for the 1910 fires.

Case Study 2: Early 20th Century Fire and Forest Conditions on the North Santiam River, Oregon

We used a multiproxy approach to assess fire effects and forest recovery along a 40 kilometer stretch of the North Santiam River near Detroit, Oregon (Figure 5). Early 20th century forest surveys mapped extensive patches of stand-replacing fire in this area, much of which reburned in the 2020 Beachie Creek and Lionshead fires (Reilly et al. 2022). Elevations range from 300 to 1,200 meters, with the Douglas-fir/western hemlock zone common at lower elevations and the Pacific silver fir zone at upper elevations (Franklin and Dyrness 1973).

To assess post-fire forest recovery in the study area, we leveraged historical and modern aerial photography, forest condition maps from the 1900s and 1930s (Thompson and Johnson 1900, Harrington 2003), opportunistic written fire records from the Willamette National Forest (Rakestraw and Rakestraw 1991), and oblique landscape photos taken in 1937 (The Nature Conservancy, 2024). Historical air photos were comprised of 82 overlapping low-altitude nadir aerial photos from 1939, prior to the construction of the Detroit Dam in 1953, which were acquired and scanned by the University of Oregon library. Each photo was manually georeferenced by locating stable ground control points from modern aerial imagery and bare-earth LiDAR data, such as rocks and road intersections, and applying thin plate spline transformations in QGIS (QGIS Development Team 2024).

Once the aerial photos were scanned and georeferenced, we distributed 146 random 1-hectare square plots with 150-meter minimum spacing in areas with evidence of potential stand-replacing fire (i.e., mapped as seedling-sapling or small Douglas-fir in the 1930s), excluding sites with evidence of logging in 1939 imagery. At each plot, photo interpreters estimated live forest cover in 1939, 1992, and 2021, using georeferenced 1939 imagery and other high-resolution imagery available in Google Earth. Plots were distributed evenly between two interpreters, with 50 plots remeasured by both interpreters to assess agreement. We then plotted kernel density estimates in R (R Core Team 2023) using ggplot2 (Wickham 2011) to compare changes in the distribution of live forest canopy cover between 1939, 1992, and 2021.

Case Study 3: 19th Century Fires and early 20th Century Forest Conditions in the Oregon Coast Range

We used a multi-century dendrochronological or “tree ring” record of historical fires developed from cambial fire scars on the Elliott State Forest (ESF) to assess historical reports of fire in the central Oregon Coast Range (Merschel 2023), in a 1600 km^2 landscape near Reedsport, Oregon. Most of the area is occupied by forests in the Douglas-fir/western hemlock zone (Franklin and Dyrness 1973). The Sitka spruce zone occurs in a small portion of the fire history reconstruction area along the western part of the study nearest to the coast. Historical reports and maps describe multiple large, high-severity fires in this area in the mid-19th century including the Yaquina fire circa 1849, the Nestucca fire circa 1852, and the 1868 Coos Fire (Munger 1930, Morris 1934, Juday 1976, Zybach 2004). Subsequent inventories map most of the area as burned by stand-replacing fire prior to 1900 (Figure 6; Thompson and Johnson 1900).

The ESF tree ring fire history was developed from 14 sample sites placed in clear-cuts on an approximate 10-kilometer grid (Figure 6). Historical fires were reconstructed to their precise calendar year of occurrence at each grid point. Historical fire years were directly evidenced by cambial fire scars on cross sections removed from 15-20 stumps and logs at each site. Cambial fire scars are a distinct fire-caused injury to a tree bole that can be readily distinguished from other damage and disturbance processes including mechanical damage from storms or damage from biological disturbance agents (Smith et al. 2016). After cross sections were collected, they were sanded to a high polish to allow cross-dating of annual rings. Cross-dating is a technique that leverages the sensitivity of annual tree ring growth to climate to precisely assign individual tree rings and cambial scars to their year of formation. Cambial fire scars were identified using criteria and methods described in Merschel et al. (2024).

Maps of historical fires were compared to the tree ring record of fire years at the ESF. We examined whether the relatively well-documented and precisely-mapped Coos fire of 1868 aligned with cambial fire scars in the ESF tree ring record. We also used the multi-century tree ring record of historical fire years to evaluate whether historical fire maps included one fire or the accumulation of several fires in the decades that preceded the development of historical fire maps.

Results

The final database included perimeters of fires and burned areas from 25 different sources with varying limitations and degrees of spatial and temporal confidence (Table 1). The database includes over 7,300 unique patches, 125,000 km^2 of burned area, and 1,200 years of fire history (Table 2). Over half of the burned area was mapped based on the estimated age of cohorts that established between 780 C.E. and the early 1900s, including extensive studies across the Olympic Peninsula (Henderson et al. 1989), northern Washington Cascades (Hemstrom and Franklin 1982, Henderson et al. 1992), and Oregon Coast Range (Juday 1976, Teensma et al.

1991, Impara 1997). The earliest direct-evidence sources were photo-interpreted perimeters in the mid-1800s in the Olympic Peninsula (Henderson et al. 1989), although high-confidence records remained rare until the early 1900s. In the 20th century, perimeters were dominated by state- or region-wide forest condition maps in 1900 (Thompson and Johnson 1900, Plummer et al. 1902), 1914 (Elliott and Rowland 1914), and the 1930s (Harrington 2003), which accounted for 69% of fires and burned areas. Fire atlases made up 15% of all recorded fire area in the 1900s, including the Cox map of the 1902 Columbia River fires (Cox 1902) and the region-wide Plummer map of the 1910 fires (Plummer 1912). Lower-confidence compiled datasets made up the majority of fire area in the mid-late-1900s as availability of other source types decreased.

The database includes a number of well-documented large fires, such as the 1902 Columbia River fires (including the Yacolt Burn), the 1933 Tillamook Burn and subsequent reburns, and the 1868 Coos and Yaquina fires. Named "mega-fires" that exceeded 40,000 hectares accounted for 38% of the recorded fire area across the westside since 1850, excluding forest condition maps (Table 3). Relatively small fires (<5,000 hectares) accounted for 30% of burned area in the same group.

Case Study 1: The Great Fires of 1910

Plummer (1912) documented 109 fires across the westside in 1910 (Figure 3A), suggesting an event that burned a comparable area to other large fire events, but that was distributed over many smaller fires (Figure 3C). As mapped, the 1910 fires cumulatively burned an estimated 370,000 hectares with a mean fire size of only 3,400 hectares and a maximum size of 26,000 hectares. In comparison, the 2020 Labor Day fires burned 335,000 hectares over 12 fires with a mean size of 28,000 hectares and a maximum size of 75,000 hectares (Eidenshink et al., 2007). Based on historical climate reanalysis data, some of the 1910 fires burned under drier and similarly windy conditions to other much larger, wind-driven fires like the Yacolt Burn and Dole Vale reburn, but winds were notably milder than the other fire events (Figure 3B).

When comparing the Plummer fire census with other historical datasets, we found a number of inconsistencies and disagreements. In some examples, large fires (>30,000 hectares) mapped by Plummer were mapped as unburned four years later (Figure 4A; Elliott and Rowland 1914). In other cases, perimeters mapped by Plummer corresponded well with the shape of nearby 1910 fires mapped from other fire atlas sources (BLM, 2020), but were displaced by kilometers with areas more than doubled (Figure 4B). Of the 163,000 hectares of fire mapped on federal forests in the Oregon westside in 1910, only 28,000 hectares (17%) was mapped as burned in the 1914 forest survey (Elliott and Rowland 1914). In the 1930s, twenty years following fire, over half of the mapped burned area was inventoried as either large or old-growth trees (Harrington 2003). These inconsistencies suggest that the size of the 1910 perimeters was overestimated due to the small mapping scale.

Case Study 2: Early 20th Century Fire and Forest Conditions on the North Santiam River, Oregon

Burned areas mapped in the early 1900s suggest stand-replacing fire across scattered parts of the North Santiam River study area, including the eastern extent as well as the slopes north of the river in the area that is now Detroit Lake (Figure 5A). There is strong evidence for additional fires in the region between the 1900 mapping and the 1930s, corroborated by extensive seedling/sapling cover in a subsequent forest inventory (Harrington 2003), widespread snags in 1937 oblique photos and 1939 aerial photos, and written records of small unmapped fires that correspond with nearby landmarks (Rakestraw and Rakestraw 1991; Figure 5A), including the Sardine Mountain Fire (1902; 400 ha), the Breitenbush Fire (1914; 800 ha), and the Detroit Fire (1919; 2,400 ha).

Agreement on classification of forest structure was high between observers with only occasional differences in estimates of canopy cover (R^2=0.79) that were due to the use of different photos with minor misregistration between photos. A comparison of canopy cover values over time shows a distinctive shift from a landscape covered primarily by open early seral conditions (i.e., open forest prior to canopy closure) in 1939 (86% of plots with <40% canopy cover; Figure 5C) to one dominated by closed canopy forests in 1992 (5% of plots with <40% canopy cover; Figure 5C). Following the 2020 Beachie Creek and Lionshead fires, 66% of the interpreted plots were in open, early seral conditions with 34% in closed canopy conditions. Only 25% of the plots with closed-canopy conditions (>60% canopy cover) in 1939 (2.7% of all plots) persisted through the 2020 fires with closed-canopy conditions.

Case Study 3: 19th Century Fires and early 20th Century Forest Conditions in the Oregon Coast Range

Fire records and tree establishment data from tree ring reconstruction sites in the central Oregon Coast Range document relatively frequent mixed-severity fires, with each site recording 3-7 fires per century between 1750 and 1910 (Figure 6B). While extensive fires were recorded in 1776 (29% of sites), 1849 (50% of sites), and 1868 (29% of sites), most fire years were documented by cambial fire scars at only one site suggesting most historical fires were smaller than the grain of the sample sites.

The patches of “stand-replacing” fire mapped by Thompson and Johnson (1900) generally align spatially with tree ring records of fire in 1849 and 1868. For example, the 1868 fire was mapped north and south of the Umpqua River and encompassed most of the Elliott State Forest apart from the central portion of the forest (Figure 6). The tree ring records of fire generally match this pattern, and notably did not detect fire in 1849 at site LF10, which was mapped as unburned in the 1900 survey (Thompson and Johnson 1900).

Discussion

Our fire history database offers a broad look at historical fire activity across the westside, compiled from 25 individual sources and spanning 13 centuries and over 125,000 square kilometers of burned area. The collection centers on high-severity fire between the late 19th and early 20th centuries, including well-known mega-fires like the Yacolt Burn and Tillamook Burn in addition to smaller, previously unpublished perimeters, and provides broader historical context for the preceding centuries. Fire perimeters were compiled from both contemporary historical sources from the early 20th century as well as retrospective surveys and studies from the mid-late 20th century, and represent a broad range of methodologies and objectives with unique constraints and limitations. While the database is far from a complete or unbiased record of westside fire, users can leverage metadata, judge spatiotemporal confidence, and review example case studies to identify appropriate applications that work within the strengths and weaknesses of each source.

Fire atlases, typically collected shortly after an event to document specific impacts like the Cox 1902 map of the Columbia River Fires, represent the highest confidence perimeters in the database which can be used to study individual events or to corroborate other broader datasets. Even so, fire atlases collected by different observers of the same event can show substantial disagreement, as we found in the 1902 Yacolt Fire (Figure 2), and small mapping scales can exaggerate the size of individual perimeters in regional events like the Great Fires of 1910 (Figure 4). In those cases, identifying primary sources and comparing mapped perimeters with corroborating evidence like subsequent forest condition maps helped to select final versions.

Compared to fire atlases, photo-interpreted perimeters offered similar spatial detail, but generally approximated fire years based on post-fire structure and were limited to the mid-20th century. The high spatial confidence of these perimeters can be leveraged opportunistically with fire atlases to investigate patterns of fire severity and post-fire resilience based on interpretations of forest structure.

Cohort-based sources (e.g., Teensma 1991 and Henderson 1989) rely on indirect evidence of fire such as even-aged cohorts of Douglas-fir, ostensibly established shortly after fire, providing relatively coarse information over a broad temporal scale. Spatial precision for these maps is generally low as they were typically delineated based on forest structure observed in aerial photographs acquired centuries after fire, and likely overestimate patch sizes and underestimate spatial heterogeneity as a result. Temporal precision is similarly low due to the variability in the timing of post-fire cohort establishment, and only directly indicate a lower bound on fire years. Fire years derived from estimated tree ages are typically accurate to within 25 to 50 years, but several studies across the region document establishment periods over several decades to a century (Poage et al. 2022, Freund et al. 2014 Tepley et al. 2014). These longer multi-decadal establishment periods most often arise from field dating errors on minimally prepared stumps (Weisberg and Swanson 2001, Tepley et al. 2014) and because reburns of historical fires result in the establishment of multiple cohorts over several decades (Merschel et al. 2024). In addition, large burned patches may require multiple seed crops to fully re-colonize, which can occur at irregular intervals due to inconsistent favorability in environmental conditions (Eis 1973, Reukema 1982). Systematic studies of cohort ages like those included in the Olympic Peninsula and Washington Cascades offer a long-term view of broad-scale fire activity, but struggle to distinguish extremely large fires from the combination of many fires over a relatively short period.

Forest condition maps like Plummer et al. (1902) represented unique primary sources with consistent and systematic mapping of fire activity at regional scales. These early 20th century efforts to map burned areas give large-scale estimates of burned areas based on early seral conditions associated with high-severity fire. The areas mapped as burned represent "only those in which the destruction of timber was nearly or quite complete"; burned areas with only partial destruction of the timber were not mapped (Thompson and Johnson 1900, Gannett 1902). Because fires are mapped retrospectively based on forest structure using relatively crude surveying techniques, individual perimeters can represent multiple overlapping fires with unknown years. However, these sources provide a uniquely comprehensive geographic context that can capture cumulative fire effects and facilitate broader inference about landscape heterogeneity and the extent and distribution of early serial habitat in the early 20th century (Reilly et al. 2022). Additionally, these datasets provide a consistent, if imperfect, validation of other more geographically specific sources.

Finally, compiled sources like those acquired from BLM (Bureau of Land Management 2020), Oregon Department of Forestry (2020), and USFS (USDA Forest Service 2017) include a combination of other source types, but often lack metadata or clear provenance that would allow for confident interpretation and application. While these datasets are neither methodologically consistent nor systematic, they can help to fill knowledge gaps and corroborate other sources, as we found when comparing 1910 perimeters from the BLM dataset (2020) with those mapped by

Cox (1902). Given the nuances of compiled sources, they may be most effectively used with other source types in areas with high agreement among proxies.

The diversity of source methods and objectives included in the database can facilitate a wide range of research and management applications, but also require users to be both cognizant of individual dataset limitations, and cautious when viewing multiple sources in aggregate. Crucially, the database is neither a complete nor a systematically-sampled representation of westside fire history, and users should avoid extrapolating temporal trends or spatial distributions from the included perimeters. Additionally, small and low/mixed-severity fire is inherently more difficult to map, and often less incentivized to record, than large high-severity burns. Effective applications of the database should consider the limitations of individual datasets, combine sources with complementary strengths, and focus on perimeters as a record of where high-severity fire occurred, rather than where it did not.

Case Study 1: The Great Fires of 1910

As mapped, the 1910 event appears highly unique within the historical westside fire record. Despite including no remarkably large fires—the largest was less than half the size of other large historical fires (Table 3)—the geographic extent and cumulative scale based on the mapped fire perimeters exceeded other well-known historical events including the 1902 Yacolt Burn, 1933 Tillamook Burn, and 2020 Labor Day fires. However, lack of agreement with subsequent forest condition maps and contemporary reports—Morris (1934) states that western Oregon and Washington "escaped widespread fire destruction" during the 1910 event, in comparison to Idaho and Montana—suggests substantial overestimation in area burned, and reinforces the challenge of comparing datasets generated with different methods and requirements.

Despite the likely overestimation of area burned, the number and extent of fires in 1910 suggests the potential for large, regional fire events given the right combination of widespread lightning and anthropogenic ignitions, low fuel moisture to allow burning (Diaz and Swetnam 2013), and dry windy conditions to spread small fires (Figure 3B). While climate reanalysis data suggests the 1910 fires burned under drier and similarly windy conditions to other large fires like the Yacolt Burn and Dole Vale reburn, the 1910 fires appear to represent a different sort of event characterized by numerous small and medium sized fires (<25,000 ha) compared to recent and historical "mega-fires" characterized by one or a few extremely large fires (>40,000 ha).

Case Study 2: Early 20th Century Fire and Forest Conditions on the North Santiam River, Oregon

Aerial and oblique photos in the late 1930s support the existence of widespread fire-created early seral landscapes along the North Santiam River (Figure 5A), corroborating the extent of burned areas mapped in early 1900s forest condition surveys. While these maps were a valuable tool for identifying this fire-affected landscape, their lack of spatial and temporal precision necessitated secondary data sources for finer-scale analysis. Photo interpretation allowed us to refine coarsely-mapped burned patches and quantify residual tree cover, while written records helped to determine whether extensive burned areas arose from a few large high-severity fires or many smaller fires and reburns. In this landscape, available written records documented only the occurrence of relatively small fires preceding the early 1900s surveys, and we found no spatial or written evidence of notable high-severity fires like the Beachie Creek and Lionshead fires that burned through in 2020. This does not preclude the occurrence of such an event prior to 1902, but available information suggests the early seral landscape conditions were likely shaped by multiple small fires and reburns.

Change in canopy cover between 1939 and 1992 show a landscape transformation from open, early seral conditions to continuous closed canopy forests. The widespread extent of area mapped as “Douglas-fir Seedling/Sapling” (i.e., “forests in which most of the trees are 6 inches and under in diameter”; Harrington 2003) and absence of “Deforested burns” (i.e., “lands not cut over on which the stand has been killed by fire”) in the 1930s suggest rapid regeneration across the landscape. Studies on post-fire vegetation following historical and contemporary fires generally document a prompt regeneration response and resilience to single large, high-severity fires in westside forests. For example, conifer regeneration was abundant and rapid following early 20th century fires like the 1902 Yacolt Burn and 1933 Tillamook Burn (Isaac et al. 1938, Gray and Franklin 1997, Harrington 2024), and regeneration studies following contemporary fires demonstrate similar forest resilience (Larson and Franklin 2005, Brown et al. 2013, Dunn et al. 2020, Laughlin et al. 2023). Over the next 87 years, the landscape transformed from an open early seral landscape to one dominated by continuous closed-canopy conditions with only 4% of the initial 71% open early seral remaining, reflecting a larger decline in post-fire early seral conditions across the region (Reilly et al. 2022). However, extensive stand-replacing fire during the 2020 Beachie Creek and Lionshead fires has returned most of this landscape to the widespread early seral conditions of the early 20th century.

Case Study 3: 19th Century Fires and early 20th Century Forest Conditions in the Oregon Coast Range

The tree ring fire record at the Elliott State Forest illustrates a frequent, mixed-severity fire regime characterized by several relatively small non-stand-replacing fires recorded at individual sample sites, as well as infrequent high-severity fires that burned during extreme east wind events (Figure 6). While early 20th century maps of burned areas and forest conditions (e.g., Thompson and Johnson 1900) accurately describe snapshots of forest and post-fire conditions in these areas, they fail to capture the disturbance dynamics and fire regime that developed those conditions. Burned areas mapped in the early 1900s in the Oregon Coast Range likely represent the accumulation of both large 1849 and 1868 fires and dozens of smaller fires of mixed severity.

Precise dates of historical fires based on cross-dated field observations combined with maps of historical forest conditions help describe a nuanced fire regime in these moist Douglas-fir forests of the central Coast Range, where extensive stand-replacing fires occurred in the context of smaller and more frequent mixed-severity fires. Relatively small reburns of the 1849 and 1868 fires in the ESF fire history reconstruction are consistent with a pattern of reburning observed following the Yacolt Burn and Tillamook Burn (Juday 1976, Gray and Franklin 1997).

The pattern of reburning observed in Douglas-fir and western hemlock forests has important implications for interpreting cohort data used to estimate fire perimeters in the database generated by this study. After the 1849 fire, Douglas-fir establishment continued within the fire perimeter until the cessation of reburns and fire exclusion in the early 20th century. Several studies of Douglas-fir establishment have similarly documented that long establishment periods of Douglas-fir trees are common across the western Cascades and Coast Range (Poage and Tappeiner II 2002, Freund et al. 2014, Tepley et al. 2014, Merschel et al. 2024). These long periods of Douglas-fir establishment have been interpreted as evidence of an extensive high-severity fire events (Hemstrom and Franklin 1981) that created long distances to seed sources and unsuitable conditions for tree establishment. Recent cross-dated reconstructions of tree establishment (Tepley et al. 2014) and historical fires in the Oregon Coast Range (Merschel 2023) and Cascade Range (Johnston et al. 2023, Merschel et al. 2024, Johnston et al. 2026) support an alternative hypothesis that reburns and frequent mixed-severity fire occurring in the interim between infrequent severe fires resulted in long establishment periods of Douglas-fir. Overall, tree cohort data, especially from coarsely-aged field counts of stumps, likely omit evidence of historical fires and understate the complexity of early seral forest dynamics that were driven by undocumented reburns and mixed-severity fires.

Conclusion

Our fire perimeter and burned area database offers a centennial-scale look at fire history in western Oregon and Washington. Combining data sources with varying temporal and spatial coverage and confidence introduces challenges, but also provides opportunities to mitigate uncertainty by finding corroboration in multi-proxy approaches, shedding new light onto historical fire regimes. Large, well-known "mega-fires" like the Yacolt Burn and Tillamook Burn composed a substantial fraction of area burned in the mid-19th and early 20th century, but became increasingly rare in the following decades as recorded fire area gradually decreased into the 1950s, while smaller fires contributed to landscape heterogeneity throughout the recent fire record.

Like any historical record, the perimeters in this database inevitably represent an incomplete view of history, biased primarily towards large, high-severity events that impacted areas populated by Euro-American settlers, while likely overlooking smaller mixed-severity fires and non-stand replacing effects that represent a substantial proportion of contemporary westside fires (Reilly et al. 2022). Applications of this database can be most effective by focusing on observing where fires were mapped, rather than where they weren't, and looking for corroboration both between sources and with ancillary datasets like historical aerial photographs, climate reanalysis, and primary records to highlight uncertainty and increase confidence.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The spatial database is publicly available at https://doi.org/10.5281/zenodo.19120166.

Author Contributions

AZ: Conceptualization, Methodology, Formal analysis, Data curation, Visualization, Writing – Original draft, review, and editing. **MJR**: Conceptualization, Methodology, Formal analysis, Supervision, Visualization, Writing – Original draft, review, and editing, Funding acquisition. **AGM**: Conceptualization, Methodology, Formal analysis, Visualization, Writing – Original draft, review, and editing. **CAH, PDT, GPJ, PI, RJD, AWD**: Data Curation, Writing – Review and editing.

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Figures

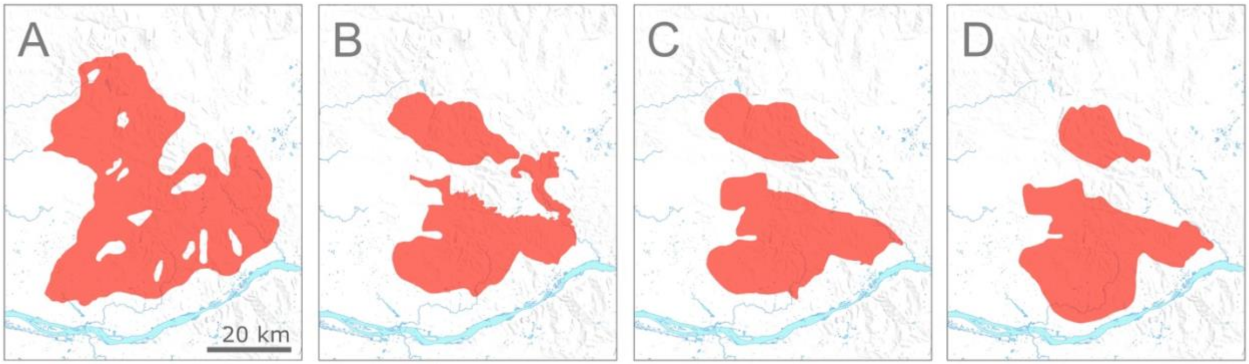

Figure 1. A) Mapped fire perimeters and burned areas across forested westside ecoregions up to 1984, color-coded by the original source type. Areas are tabulated by ecoregion/state and B) century and C) decade. The Olympic Peninsula (OP), Coast Range (CR), Western Cascades of Washington (WC WA) and Western Cascades of Oregon (WC OR) are outlined in grey and labeled in Panel A. Note that the database does not represent a spatially or temporally complete sample, and should not be used to directly interpret trends in area burned.

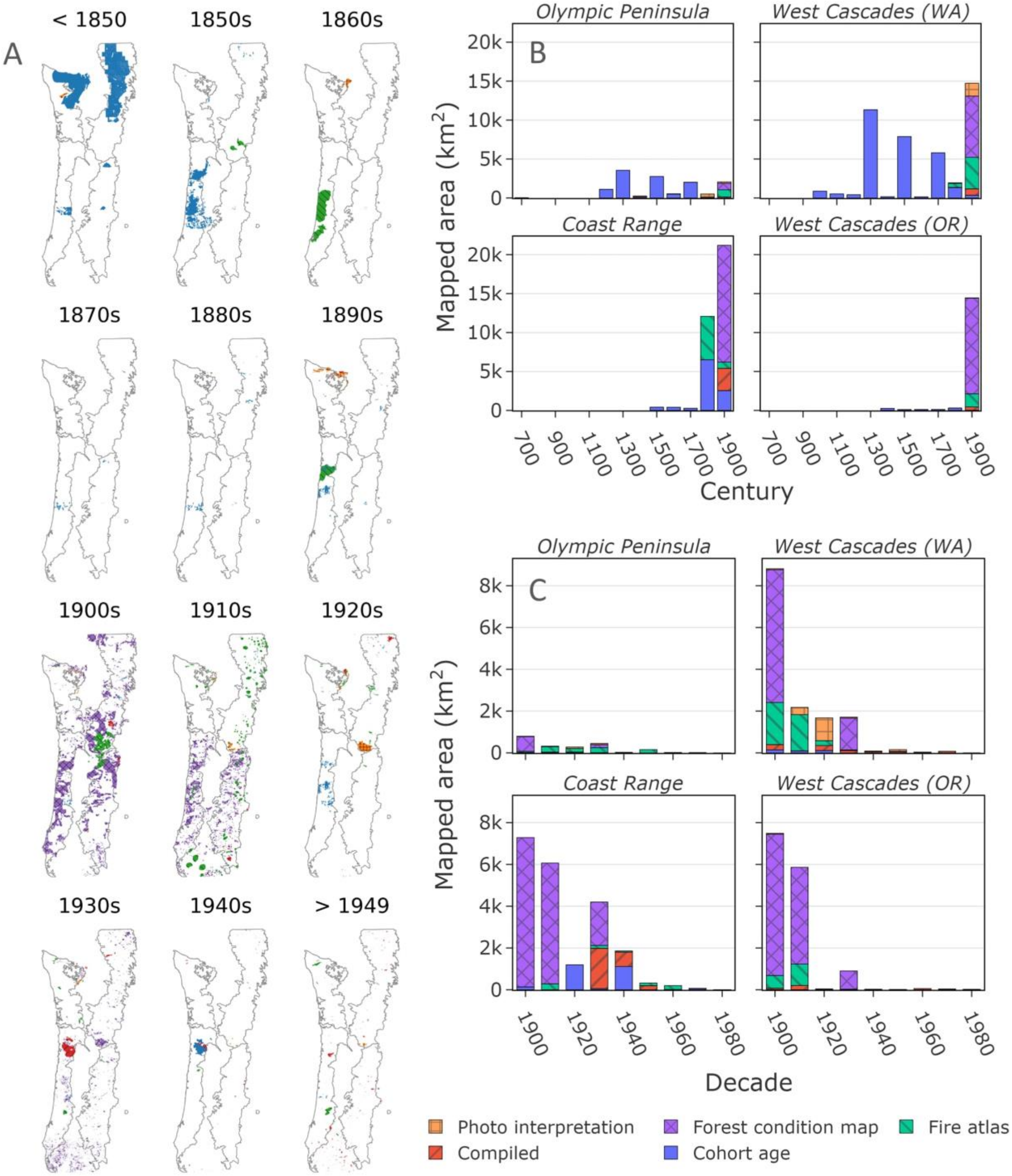

Figure 2. Conflicting perimeters for the 1902 Yacolt Burn from A) Cox (1902; fire atlas), B and C) Gifford Pinchot Fire History (2016; fire atlas), and D) Wildland Fire Decision Support System (2018; compiled). We ultimately included the Cox perimeter because it was published in a contemporary report with documentation, while the primary sources of the other datasets were unknown.

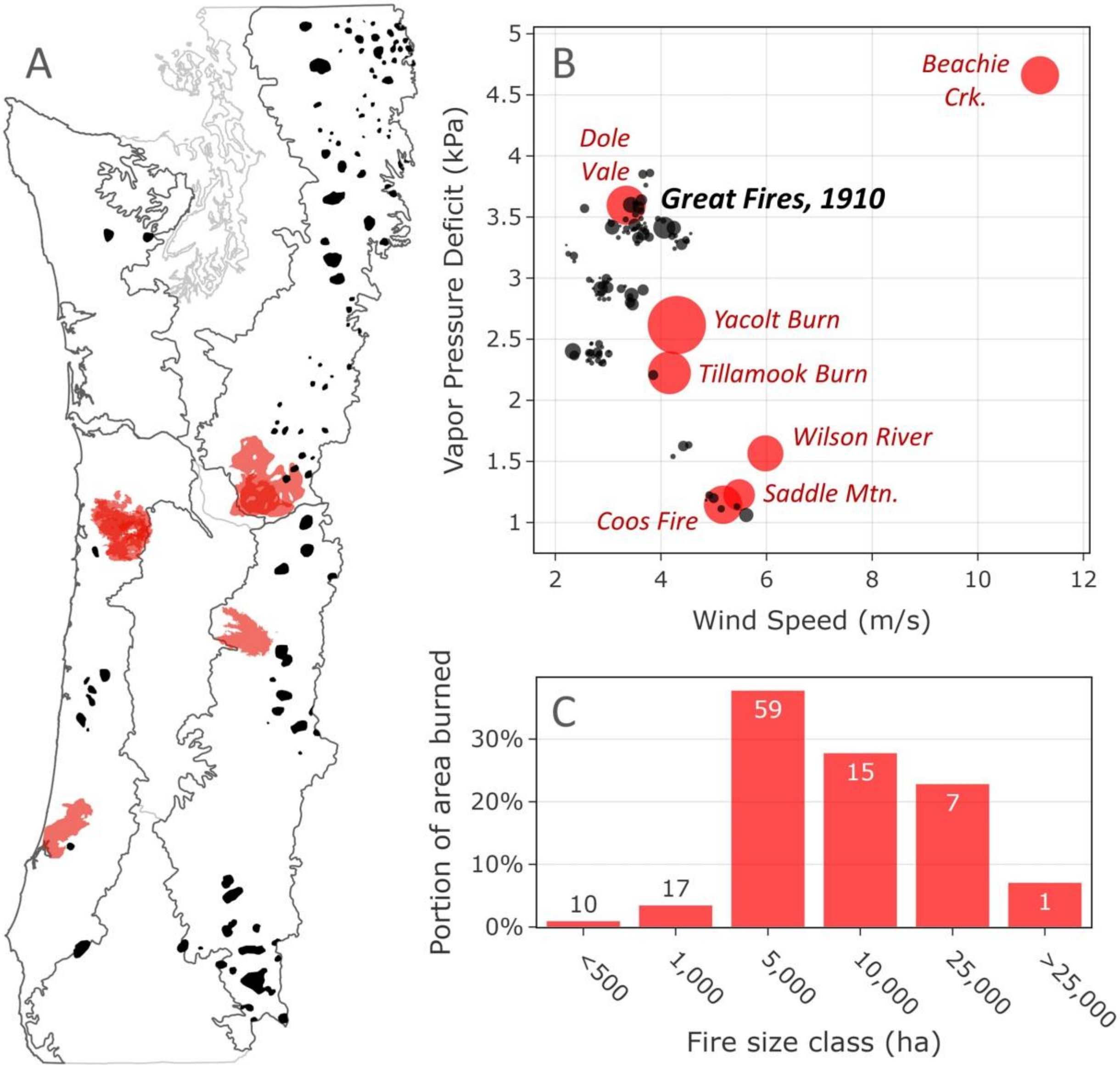

Figure 3. A) 1910 fires across the westside as mapped by Plummer (1912) in black, with other large westside fires (listed in panel B and Table 3) for comparison. Grey lines represent EPA Level III ecoregion boundaries used to define the westside study area. B) Maximum 3-hour surface fire weather at fire locations over a three-day period around the reported fire date. Black dots represent all fires in the 1910 fire event, and all dots are scaled by mapped fire size. See text for details on historical climate data. Nearby 1910 fires that fell within the same reanalysis pixel were randomly jittered for visibility. C) Portion of the total area burned by the Great Fires of 1910 by fire size class. The number of fires in each size class are labeled at the top of each bar.

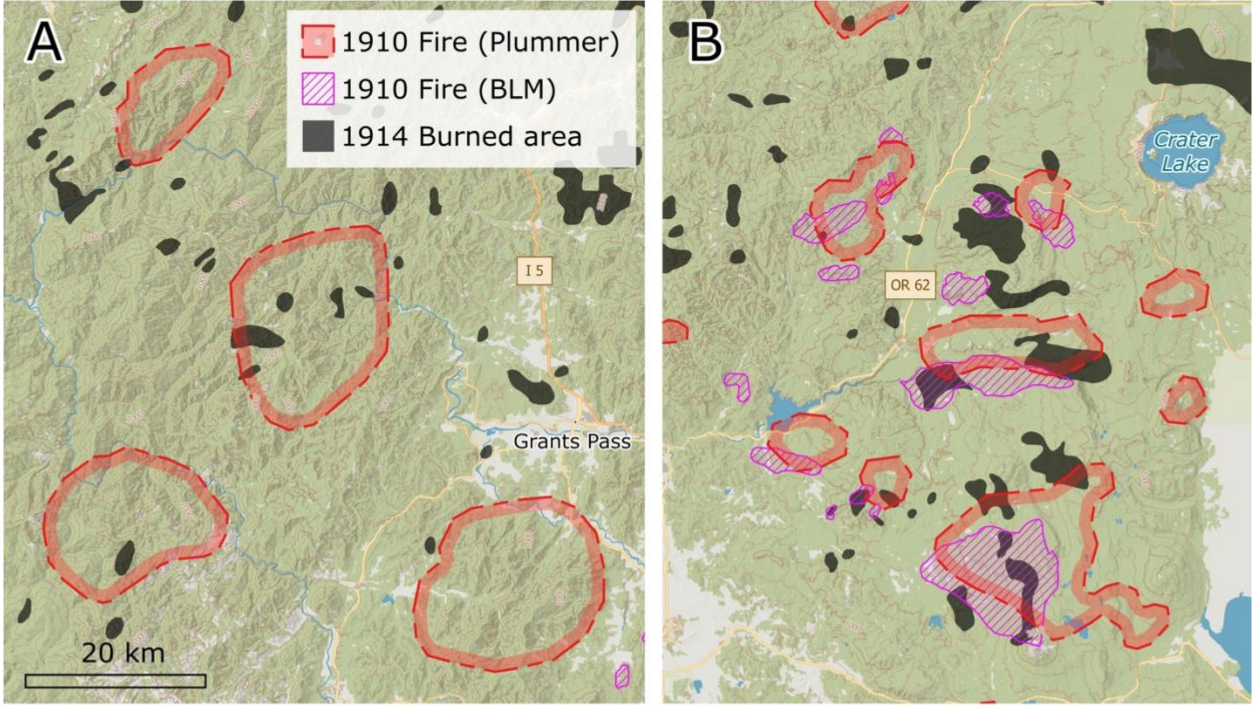

Figure 4. A) 1910 fires mapped by Plummer (1912) that were recorded as unburned in the 1914 survey (Elliott and Rowland, 1914). B) 1910 fires mapped by Plummer (1912) compared to those compiled by BLM (2020), illustrating disagreements in the size and location individual fires. The BLM dataset contained only a small number of 1910 fire perimeters, compiled from an unknown source. While Plummer (1912) offered the most complete and well-documented record of the 1910 fires, our impression is that the size of the perimeters was substantially overestimated.

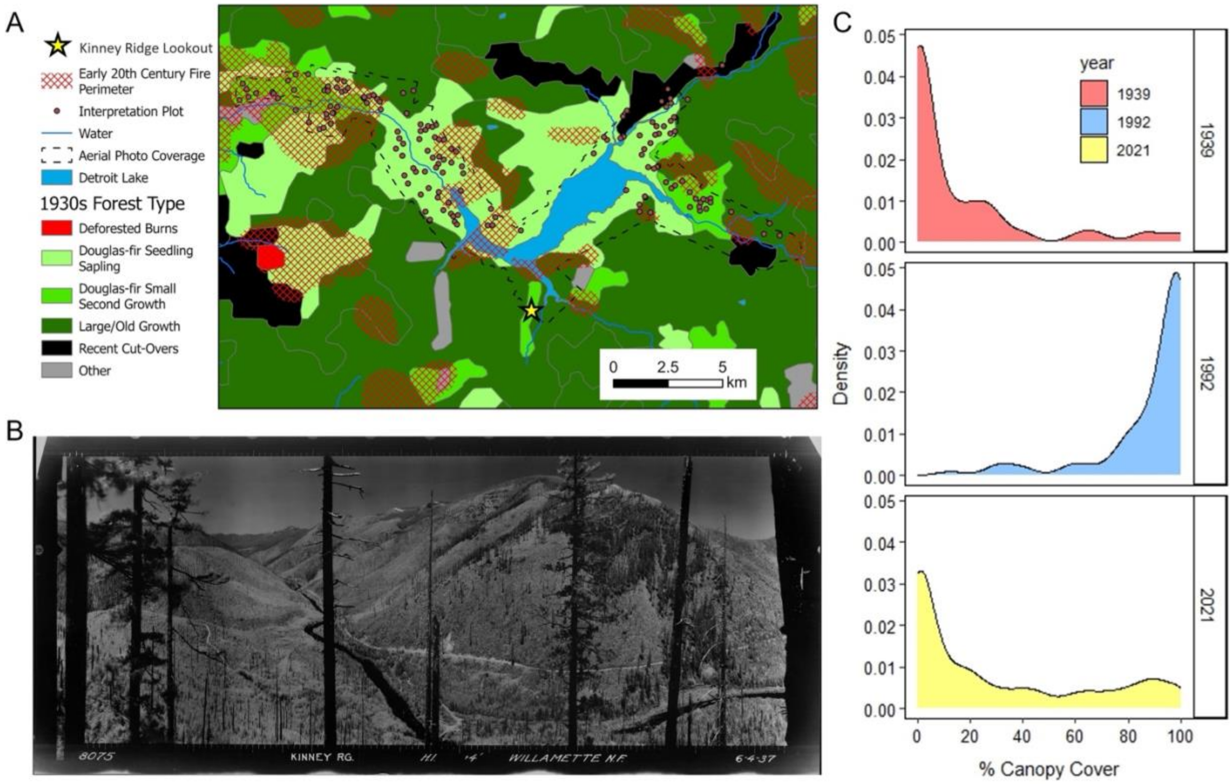

Figure 5. A) The case study area around the North Santiam River with the location of photo-interpreted plots, forest conditions in the 1930s (Harrington 2003), and early 20th century burned areas (Thompson and Johnson 1900); B) the view from the fire lookout on Kinney Ridge (yellow star on panel A) in 1937 looking northwest down the North Santiam River; C) the probability density of photo-interpreted canopy cover at plot locations in 1939, 1992, and 2021 across the area covered by available 1939 aerial photos.

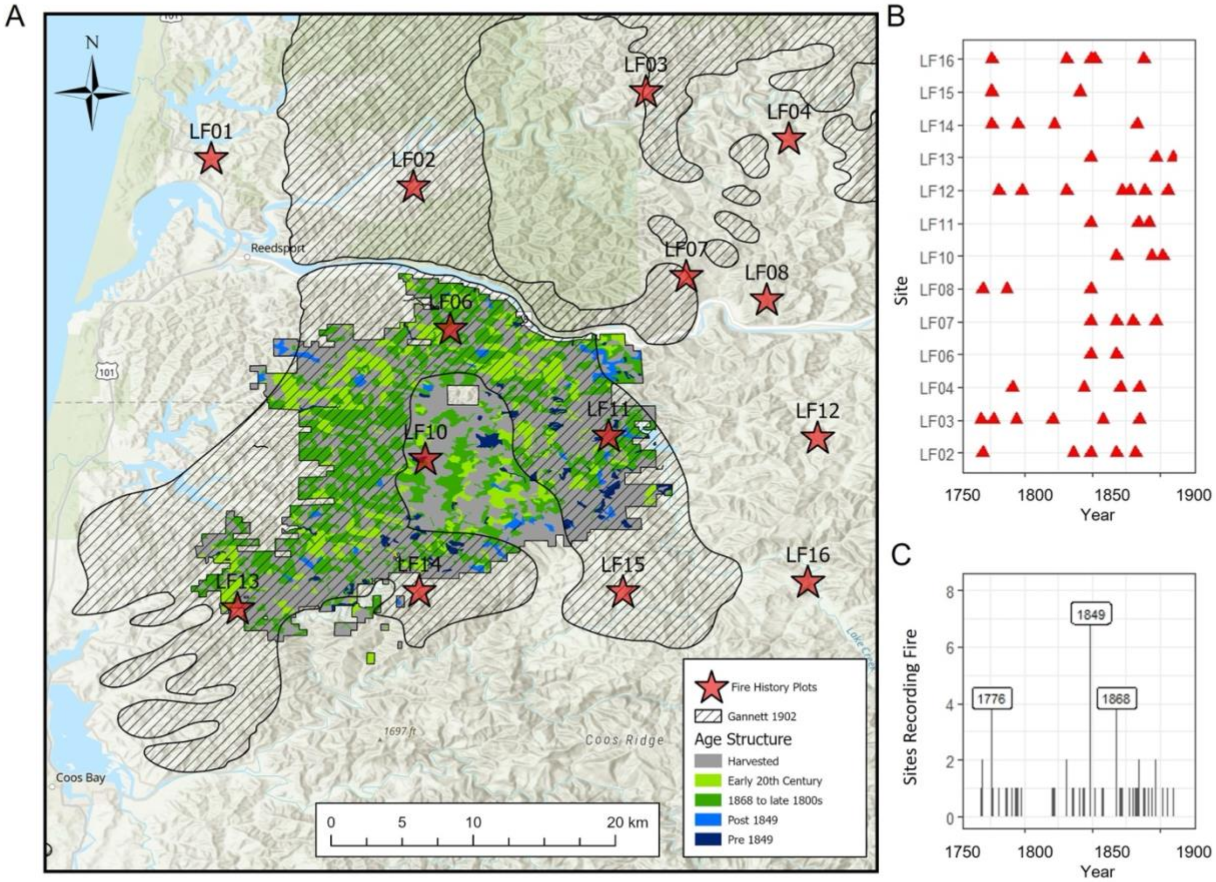

Figure 6. A) Map of burned areas near the Elliott State Forest (ESF) and the location of Fire History sites used to reconstruct historical fires. Age structure on the ESF (West and Strimbu 2024) is illustrated by color and demonstrates how stands established at different times following extensive fires in 1849, 1868, and several smaller fires in the area during the late 19th and early 20th centuries, mapped in 1900 by Thompson and Johnson. B) Records of historical fires at fire history sites on the ESF. Red triangles indicate the precise year of historical fires. C) The number of fire history sites recording fires from 1750-1920. Fires in 1776, 1849, and 1868 were extensive, but most historical fires were only evidenced at 1-2 sites. Fire history and age structure at the ESF illustrate that maps and written descriptions of historical fires may describe the effects of multiple fires in the preceding decades.

Tables

Table 1. Source types included in the fire perimeter and burned area database. Major strengths and limitations are summarized, and confidence ranges are assigned spatially (i.e., how accurately do we believe the mapped perimeters capture true fire perimeters) and temporally (i.e., how precisely do we believe the listed fire years match true fire years). Example applications suitable for each source type are listed for reference.

Source Type	Methodological Approach	Example Sources	Strength	Limitation	Spatial Confidence	Temporal Confidence	Application
Fire Atlas	Fire perimeters mapped from field surveys on the ground or remote vantage points	Cox (1902); Plummer (1912); Juday (1976)	Known fire years	Extent usually limited to single fires or fire years	Low to High	High	Studying individual fires
Photo Interpretation	Burned patches identified from forest structure	Huff (1995); Anderson et al. (2001)	High spatial accuracy	Fire years often estimated retrospectively, opportunistic sampling of fires	Moderate	Low to Moderate	Studying individual fires or surveying localized burned areas
Cohort Age	Field-based age approximations from stumps or tree cores without cross-dating	Hemstrom and Franklin (1982); Teensma (1987); Teensma et al. (1991); Agee and Krusemark (2001)	Long temporal record	Low spatial precision, perimeters may represent multiple fires, variability in cohort establishment timing	Low to Moderate	Moderate	Long-term localized records of high-severity fires

Forest Condition Maps	Burned areas mapped from field surveys on the ground or remote vantage points	Plummer et al. (1902); Thompson and Johnson (1900); Elliott and Rowland (1914); Harrington (2003)	Systematic survey of a large region	Exact fire years unknown, perimeters may represent multiple fires	Moderate	Low	Regional estimates of early seral habitat and high-severity patch dynamics
Compiled	Various combinations from other source types	BLM (2020); ODF (2020); USFS (2017); WFDSS (2018); Welty and Jeffries (2022); Welch (2021)	Additional fires not included in other sources	Unknown origins, mixed methods, indeterminate spatiotemporal accuracy	Low	Low	Fires of interest can be further investigated from other sources

Table 2. Area burned (km^2) in all mapped fire perimeters across the westside, by source type (columns) and decade (rows). Fire records prior to 1850 become relatively sparse and discontinuous, with large cohorts identified in 780, 1000, 1100, 1200, 1308, 1508, and 1701.

Decade of fire	Cohort dates	Forest condition map	Fire atlas	Compiled	Photo interpretation	*Total*
Pre-1850	46,968	-	3	1	200	*47,172*
1850	6,201	-	539	-	-	*6,740*
1860	16	-	4,112	3	309	*4,440*
1870	326	-	-	-	14	*340*
1880	498	-	-	5	20	*522*
1890	937	-	1,564	137	690	*3,329*
1900	317	25,292	2,916	363	160	*29,048*
1910	100	11,606	4,782	286	406	*17,180*
1920	1,326	-	595	379	1,215	*3,514*
1930	66	6,371	461	2,136	153	*9,186*
1940	1,118	-	52	860	36	*2,067*
1950	-	-	353	377	82	*812*
1960	-	-	225	125	1	*351*
1970	55	-	14	197	0	*267*
1980	-	-	8	48	0	*56*
Total	*57,926*	*43,269*	*15,624*	*4,918*	*3,286*	*125,022*

Table 3: All named "mega-fires" that exceeded 40,000 hectares in the database. Fires marked with * and ** reburned the Tillamook Burn and Yacolt Burn perimeters, respectively.

Fire name	Year	Location	Area (ha)	Source
Yaquina	1868	OR Coast Range	308,233	Juday, 1976
Yacolt Burn	1902	WA W. Cascades	182,028	Cox, 1902
Nestucca	1890	OR Coast Range	153,946	Juday, 1976
Coos Fire	1868	OR Coast Range	102,822	Juday, 1976
Tillamook Burn	1933	OR Coast Range	98,634	ODF, 2020
Dole Vale**	1929	WA W. Cascades	82,107	Gifford Pinchot Fire History, 2016
Saddle Mountain*	1939	OR Coast Range	79,441	ODF, 2020
Wilson River & Salmonberry*	1945	OR Coast Range	69,608	ODF, 2020