Spatiotemporal Trends in Pacific Northwest Wildfire Occurrence and Firefighting Resource Demand

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Outline

Overview and Objectives

The Pacific Northwest Wildfire Challenge

Growing Concerns:

- Rising temperatures and prolonged droughts
- Increased development at wildland-urban intersection
- More frequent and severe fire events
- Complex impacts on infrastructure and communities

The Gap:

- Traditional research focuses on burn severity or climate drivers
- Few models connect occurrence to downstream consequences
- Limited predictive frameworks for resource allocation

Research Objectives

Primary Goal: Identify spatiotemporal trends and build a predictive framework for wildfire impacts

Specific Objectives:

1. Analyze wildfire occurrence patterns (2002–2024)
2. Model relationships between fire characteristics and environmental/infrastructural factors
3. Develop Python-based predictive model for impact severity indices
4. Visualize trends using QGIS for decision-making support

Study Area: Oregon, Washington, Idaho (568,000 km²)

Data Used and Methods

Data Sources

Wildfire Activity:

- MTBS: Fire perimeters, burn severity (1984–2024)
- ICS-209: Resource deployment, suppression costs

Environmental Variables:

- PRISM: Temperature and precipitation
- TerraClimate: Wind speed
- Stanford EchoLab: Wildfire smoke PM2.5
- U.S. Drought Monitor: Drought indices

Infrastructure & Socioeconomic:

- EIA: Electricity generation, power plant locations
- CDC/ATSDR: Social Vulnerability Index (SVI)

Analytical Methods

Temporal Analysis (Python):

- Time series decomposition and forecasting
- Correlation analysis: climate anomalies vs. fire activity
- Libraries: pandas, geopandas, numpy, matplotlib

Spatial Analysis (QGIS):

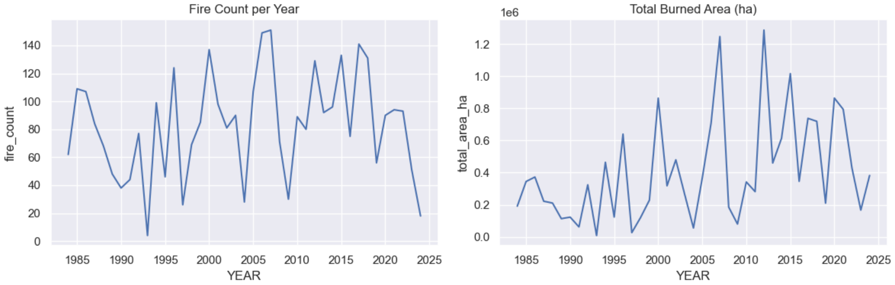
- Hotspot detection and kernel density estimation
- Raster overlay for infrastructure proximity
- Atmospheric difference mapping

Predictive Modeling (scikit-learn):

- Gradient Boosting Regressors (150 estimators, lr=0.05)
- Outputs: Resource demand, evacuation risk, structure threat, suppression cost
- Log-transform for skewed distributions

Results

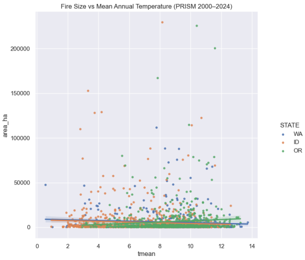
Temporal Trends: Fire Activity Over Time



Key Findings:

- Major peaks in 2006 and 2012: High fire count + large burned area
- Other peaks (2000, 2017): Many fires, but controlled burn area
- Suggests variable firefighting effectiveness across years

Climate Relationships: Temperature and Precipitation



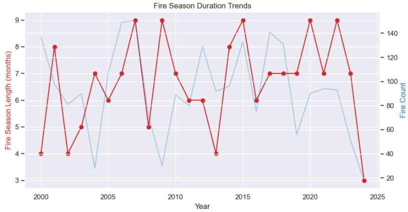
- Weak negative correlation
- High variability

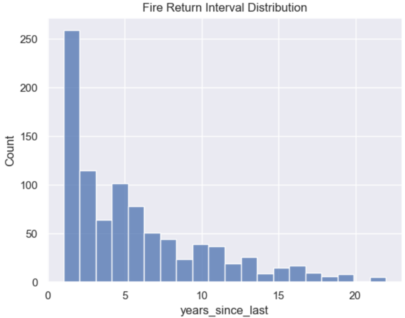
- Similar high variability
- Simple metrics insufficient

Drought Analysis:

- No significant temp difference during drought ($p=0.437$)
- Temperature and precipitation stronger predictors than drought indices

Fire Season and Reburn Patterns

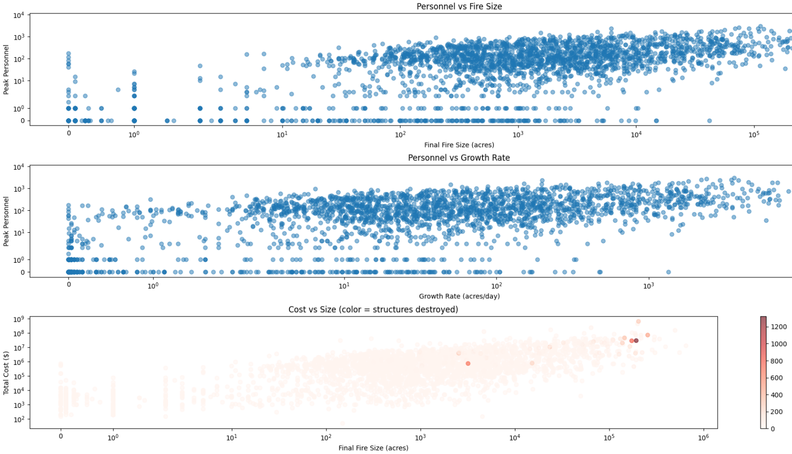




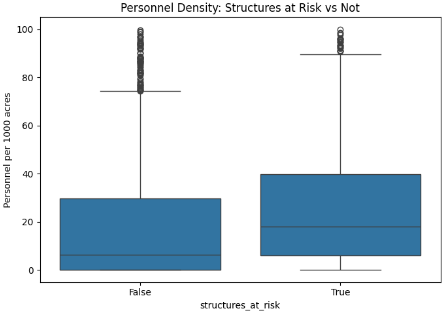
- Expanding fire season
- More active fire days/year

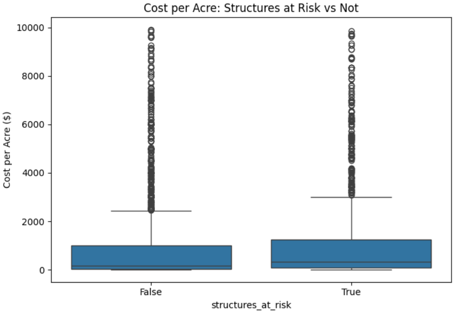
- **929 reburned areas**
- Growing prevalence
- Short-interval reburns

Firefighting Resource Deployment



Firefighting Resource Deployment

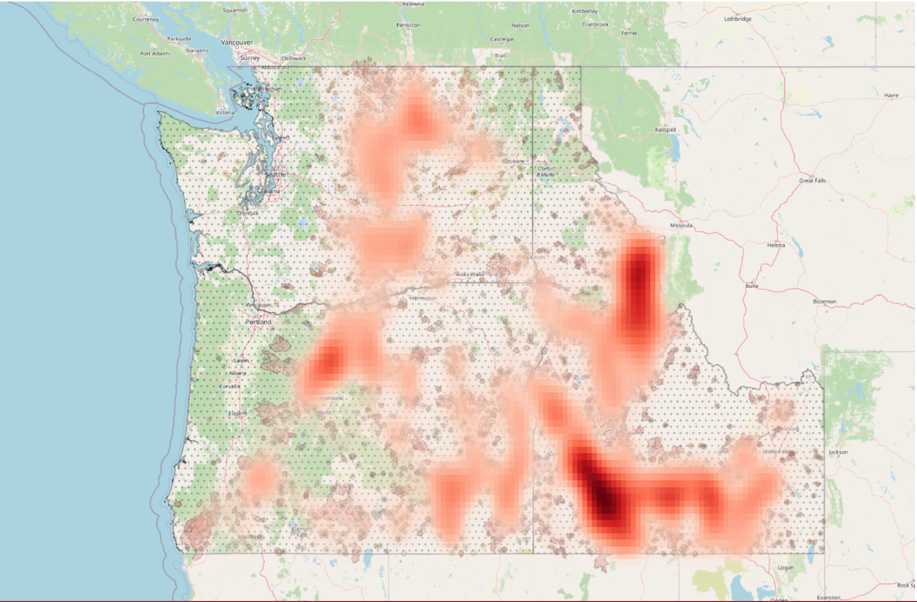




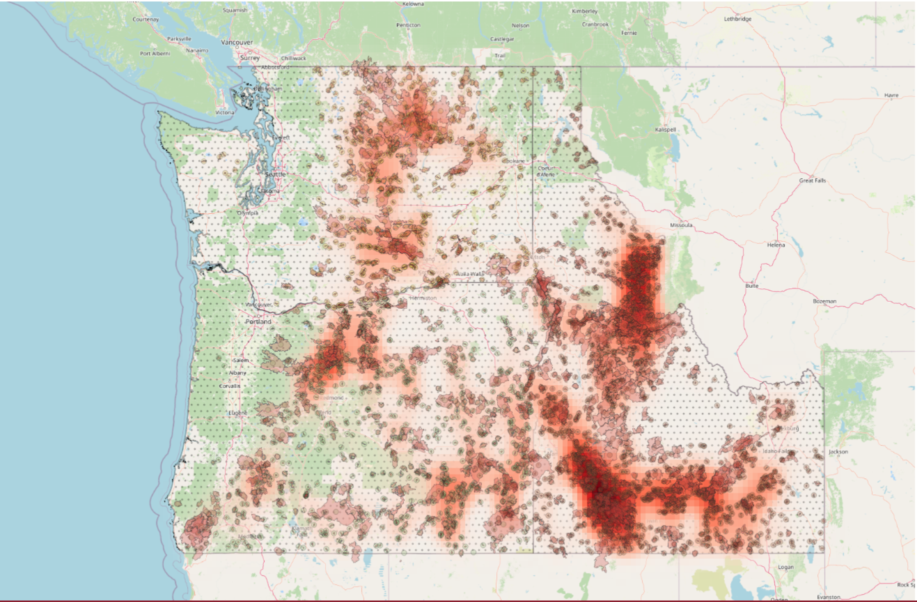
Critical Findings:

- Structures threatened: 46.8 median personnel
- No structures: 26.1 median personnel
- **Nearly double** the resources for structural protection
- 143 fires caused evacuations
- 481 fires resulted in structure loss
- Average loss rate when threatened: 7.73%

Spatial Patterns: Fire Hotspots



Spatial Patterns: Fire Hotspots



Spatial Patterns: Fire Hotspots

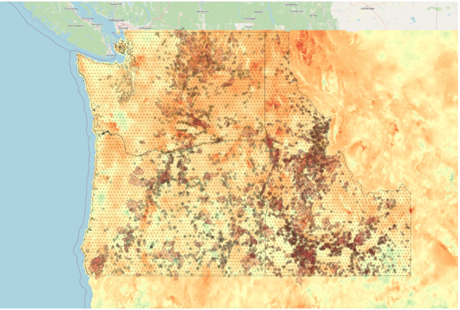
Persistent Fire Hotspots:

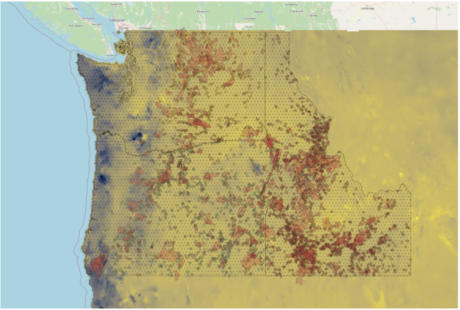
- Eastern Oregon
- Central Washington
- Southern Idaho

Characteristics:

- Dry forests, shrublands, grasslands
- High fuel loads
- Align with greatest temperature increases and precipitation declines

Climate Change Impacts





2024 vs. 2000:

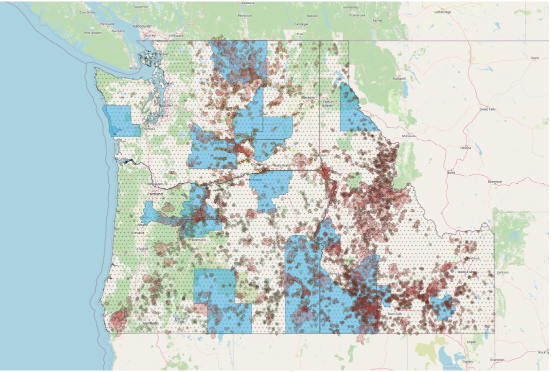
- Range: -2.91°C to +3.41°C

2024 vs. 2000:

- Range: -584mm to +2173mm

Clear spatial patterns of warming and changing precipitation align with fire hotspots

Social Vulnerability

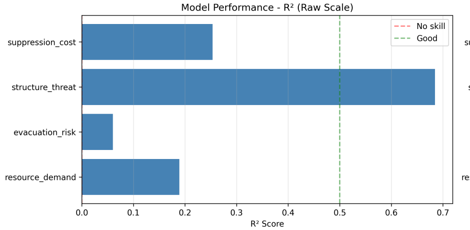


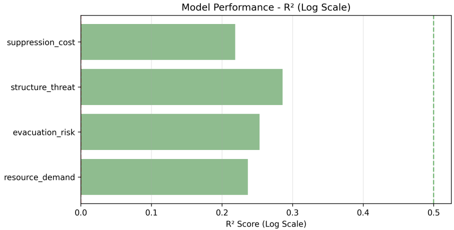
Most Vulnerable Counties:

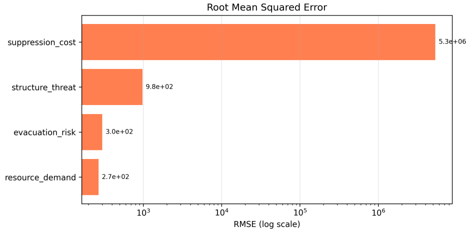
- Oregon: Malheur, Jefferson, Umatilla
- Washington: Adams, Yakima, Okanogan
- Idaho: Washington, Elmore, Gooding

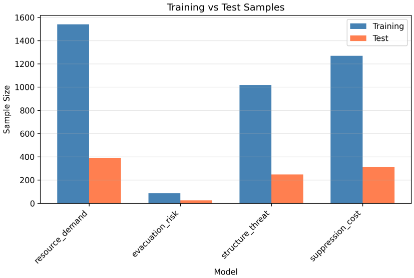
Key Finding: Highest vulnerability counties experience elevated fire exposure

Predictive Model Performance









Mean Absolute Error by Model

Actual vs Predicted Means

Predictive Model Performance

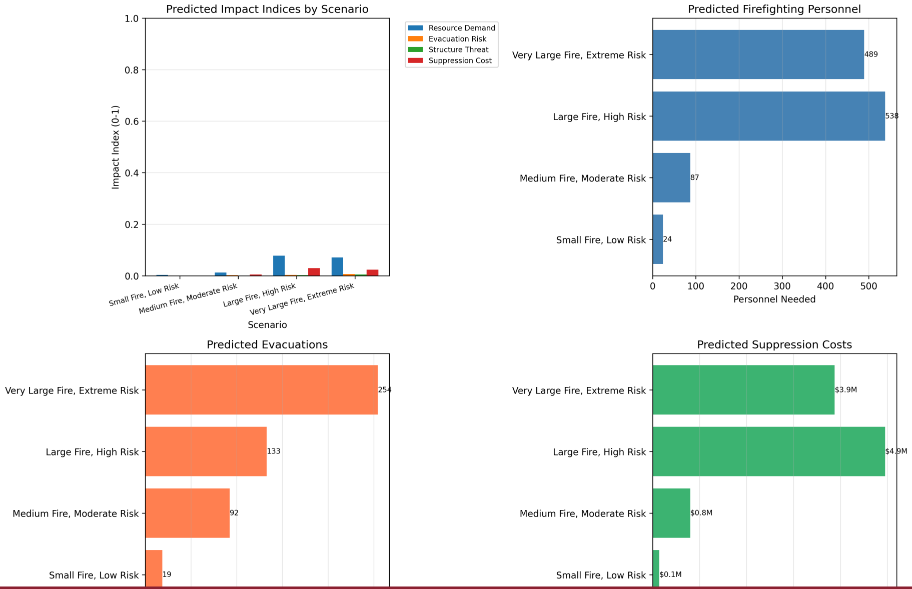
R^2 Values (Variance Explained):

- Structure Threat: 68.5% (best performer)
- Suppression Cost: 25.3%
- Resource Demand: 18.9%
- Evacuation Risk: 6.0% (poorest)

Model Architecture:

- Gradient Boosting with 150 estimators
- Learning rate: 0.05, max depth: 6
- Log-transform for skewed distributions

Model Predictions: Small vs. Large Fire



Model Predictions: Small vs. Large Fire

Small Fire (100 ha):

- 14 personnel
- 87 evacuated
- 22 structures
- $1.07M cost

Large Fire (10,000 ha):

- 538 personnel
- 133 evacuated
- 319 structures
- $4.95M cost

Model shows expected scaling with fire size, but high uncertainty in human decision variables

Highlights of Study

Key Findings

Clear Spatiotemporal Trends:

- Increasing frequency and burned area (1984–2024)
- Expanding fire season length
- 929 reburned areas identified
- Persistent hotspots in eastern PNW

Infrastructure & Social Impacts:

- Double personnel for structure protection
- Spatial correlation with energy infrastructure
- Significant disparities in vulnerability across communities
- PM2.5 exposure increased during major fire years

Model Limitations and Insights

Why the Model Struggles:

- Operational decisions involve real-time factors beyond historical data
- Political pressures and resource constraints not captured
- Evacuation orders depend on local protocols, not just fire characteristics
- High cost variability from jurisdictional differences
- I'm not great at this

What Works:

- Structure threat prediction (68.5% R^2)
- Spatial hotspot identification for resource pre-positioning
- Social vulnerability mapping for preparedness planning

Implications for Management

Practical Applications:

- Spatial hotspot analysis $\rightarrow$ firefighting asset pre-positioning
- Social vulnerability mapping $\rightarrow$ targeted preparedness programs
- Climate trend analysis $\rightarrow$ long-term resource planning
- Structure threat model $\rightarrow$ evacuation planning support

Future Research Directions:

- Incorporate high-resolution fire weather indices
- Add real-time fuel and/or moisture measurements
- Include suppression strategy data
- Extend to post-fire recovery and economic impacts
- Explore neural networks for non-linear relationships

Conclusions

This research demonstrates:

- Pacific Northwest wildfires show clear increasing trends
- Climate variables have complex relationships with fire activity
- Significant disparities exist in impact distribution
- Predicting human dimensions (evacuation, deployment) remains challenging

Central Message:

Effective wildfire management must integrate climate data, spatial analysis, and social considerations to protect communities and ecosystems.

Repository: github.com/blaiserettig/predicting-fire

Thank you!

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