Multi-Source WUI Characterization Enhanced with Machine Learning: Dynamics and Hazard Assessment

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Increasing community vulnerability to wildfires at WUI

Increasing wildfires in California (17 after 2000, 5 largest in 2020)

Expansion of housing development into the wilderness
- Creating larger WUI areas
- More than 20 million properties susceptible to wildfires
Majority of wildfire ignition started in/around WUI

- 35% within WUI
- +35% within 2km buffer
- +10% within 4km buffer
- Along major roads

Increasing human-started ignitions, due to landscape modification from 0.8 to 0.9 per km²/decade

2000 -> 2010 WUI

Chen and Jin, 2022
15 out of 20 most destructive fires occurred since 2015

More than half in the past 5 years

(2021 Dixie fire >1300;
2020 North Complex > 2000;
2018 Camp fire >18,000)
Challenging for fire risk assessment in WUI

- Heterogeneous, dynamic landscapes with human modification
- Challenging for fire behavior modeling and risk assessment

**Goal:** Multi-sensor monitoring and community fire risk assessment

1. Fine grained annual WUI characterization (human settlements and vegetation)
2. Improved understanding of WUI fire behavior and building damage
Mapping building footprints from VHR imagery via Deep Learning

- NAIP VHR imagery at 0.6m to 1m every two years since 2009
- integrated Mobile-UNet and generative adversarial network (GAN)
Building footprints identified from NAIP aerial imagery
Tracking new housing development and structure damage every two years

Huang et al., 2022
Improved mapping of WUI patterns

Lake County

Sonoma County

Orange County

Huang et al., 2022
VUI fire risk and structural damage

All WUI fire days from 2003 – 2020
Machine learning: modeling probability of building damage
Modeling risk of structure damage by wildfires

Pre-fire Building footprints

Post-fire Damage Survey (DINS)

Building damage probability (% = # damaged / # buildings)

*Intermediate scale*: within daily fire perimeter
Wildfire-caused building damage risk evaluation

All WUI fire days from 2003 – 2020
Machine learning: modeling probability of building damage
Fast moving fires caused higher building damage probability

Huang et al., in prep
Higher risk for clustered buildings than dispersed community, especially when fire spreads relatively slowly.
Variable importance for building damage risk

- Building Pattern
- Human
- Fire Behavior
- Weather
- Vegetative Fuel
- Topography

Cumulative Contribution

- Regression
- Classification

Fuels

- Population density
- Percentage of building area (log)
- Magnitude (prevail)
- Topographic Diversity
- Road density
- Travel cost to Intermix WUI
- Travel cost to Interface WUI
- Travel cost to Fire facility
- Burning Index
- SPEI 5yr
- Mean distance to nearest building
- CV of Fractal Dimension
- Annual NDVI
- NDMI Z-Score
- TreePct
- Landscape Shape Index
- VPD_Mean

Permutation Importance
Multi-sensor fine scale WUI fuel mapping

- Woody canopy fuels (shrub/tree crowns)
  - NAIP imagery at 0.6-1m since 2009
  - PlanetScope at 3m since 2017
  - NAIP + PlanetScope

- Fuel structure
  - Aerial lidar – Radar + GEDI

- Quantify fuel characteristics
- tracking fuel treatment (e.g., thinning, defensible space around houses)
Fine scale WUI canopy fuel mapping: Planetcope

- 3D convolutional neural network (CNN)
Crown scale canopy mapping from NAIP
Mask2Former (Facebook AI Research)

- Masked-attention Mask Transformer (Mask2Former), a deep network capable of addressing any image segmentation task (panoptic, instance or semantic).
- State-of-the-art (SOTA) results on several segmentation benchmarks.

Our model (SEEM) can perform any segmentation task, such as semantic, instance, and panoptic segmentation, in open-set scenarios.

Supports visual, textual, and referring region prompts in any combination, allowing for versatile and interactive referring segmentation.

[Xueyan Zou, Jianwei Yang, Hao Zhang, Feng Li, Linjie Li, Jianfeng Gao, and Yong Jae Lee. “SEEM: Segment Everything Everywhere All at Once.” arXiv, 2023. (On going work)]
Conclusions and next steps

• Deep learning based building footprints detection from NAIP aerial imagery allows for tracking WUI building dynamics every two years.

• Crown scale woody fuels mapping with Planet and NAIP was enhanced with deep learning such as CNN.

• WUI building damage was driven by rapid fire spread, building patterns, and other community related variables.

• Next steps – toward fire-safe communities
  Data fusion for scalable WUI characterization;
  Adapting more advanced deep learning framework to improve object identification
  Improved understanding of the linkages between fuels, fire behavior, and structure damage
  Tools for community fire vulnerability assessment