Title: Interdisciplinary Approaches to Modeling Extreme Wildfire Events
Short Title: Modeling Extreme Wildfires
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Project Summary
Extreme wildfire events are increasing, driven by the expansion of human populations into the wildland urban interface, historical land management practices which suppressed wildfire, and climate change. These low probability and high consequence events are neither linear nor evenly distributed across all landscapes but exhibit exceptional fire behavior characteristics and produce severe consequences for ecosystems and humans. The wildfire extension of LANDIS-II simulates the biophysical and social dimensions of fire, projecting future changes in fire ignitions, fire intensity, fuel-treatment effects, fire suppression, prescribed fires, and extreme events with climate change. However, large numbers of replicates are often needed to capture extreme wildfire events. The goal of these workshops is to form a cohesive, interdisciplinary research team of biophysical and social scientists who will work at the nexus of wildfire science to: 1) synthesize our current understanding of extreme fire behavior and their socioeconomic context, 2) isolate the current gaps in our understanding of the social and biophysical markers that contribute to extreme fire behavior and risk to communities, 3) develop a roadmap for improving the representation of social and biophysical mechanisms that drive extreme wildfire behavior, and 4) integrate LANDIS-II into HPC environments and to quantify extreme wildfire events in three landscapes (Sierra Nevada of California, interior Alaska, and the Southern Appalachians). Our work will illustrate how the improved representation of extreme events can be incorporated into forecasting tools by using the LANDIS-II model framework as a demonstration platform.

Public Summary
Extreme wildfire events are increasing, driven by the expansion of urban communities closer to forests, land management practices which suppressed wildfire, and climate change. These events have a low probability of occurring, but they exhibit exceptional fire behavior characteristics and produce severe consequences for forests and humans. While the media and field studies focus on extreme wildfire events like the Lahaina wildfire in Hawaii and the Paradise fire in California, most estimates of wildfire risk report averages, but not extreme events, and they often underestimate the effects of climate change. Our workshops will form a cohesive, interdisciplinary research team to: 1) synthesize our current understanding of extreme fire behavior, 2) isolate the current gaps in our understanding of the social and biophysical drivers that cause extreme wildfire events and risk to communities, 3) develop a roadmap for improving the representation of extreme events into models that represent social and biophysical processes, and 4) integrate a widely-used model of forest change into High Performance Computers to generate improved predictions of wildfire risk and the probability of extreme wildfire events. We will initially investigate extreme fires in the Sierra Nevada Mountains of California, interior Alaska, and the Southern Appalachians.

Introduction and Goals

Wildfire events are increasing in frequency, size, destruction, and cost. These changes are driven by the expansion of human populations into the wildland urban interface, historical land management practices which suppressed the historical ecological role wildfire has played on the landscape, and changes in the climate. These factors have resulted in a growing prevalence of extreme wildfire events; outliers at the extreme tail of a right-skewed distribution which have deviated from the typical range of variability. By nature of the biophysical conditions that give rise to these events, these events are frequently highly destructive. They fit a category documented as low probability and high consequence events and are neither linear nor evenly distributed across all landscapes. These events either exhibit exceptional fire behavior characteristics such as flares or rapid increases in rates of spread, or events that produce severe consequences for ecosystems and humans (Tedim et al., 2018). Recent examples include the 2020 Labor Day Fires in western Oregon and the 2016 Gatlinburg CT2 wildfire in Tennessee.

These events have been recognized as particularly problematic and difficult to prepare for and manage because organizations develop institutional practices and capabilities based on historical experience. As such, low probability/high consequence events have a unique risk profile. In these events, there is a greater likelihood that preparation and institutional practices will be inadequate and/or ill-suited to the task demands of the event, which may reduce the amount of time available to mobilize resources for response and increase the likelihood of problematic decision making after the event (e.g. Nowell & Stutler, 2020; Weick, 2010).

While the media and empirical studies focus on extreme wildfire events like Paradise, California (Brown, 2022), most wildfire risk assessments in the US report averages (e.g., Ager et al., 2021) and not extreme events. Also, wildfire risk is often calculated assuming the climate is stationary (i.e., no future changes in climate (e.g. https://hazards.fema.gov/nri/wildfire) and/or vegetation is static (Dye et al., 2023). Given that climatic and fire tolerances differ among species and can vary as a function of age, climate-fire interactions on vegetation are likely to create feedbacks that subsequently alter fire behavior. Also, climate change directly alters forest composition and productivity through changes in temperature and precipitation, and vegetation is unlikely to remain static over time.

Promising results to estimate wildfire risk and capture extreme events have been obtained by new wildfire spread simulation systems that can help estimate the likelihood of wildfire spread and intensity for large landscapes (e.g., million hectares) by considering historical and future climate, fuels, fire ignition patterns and regime, and associated socio-economic features. LANDIS-II, a spatially-explicit, process-based simulation model which is optimized for large-scale spatial dynamics and allows multiple ecological processes (e.g., growth, mortality, regeneration, decomposition, and disturbances) to overlap in space and time (Scheller et al., 2007). This model has been widely adopted for use in wildfire research in the U.S. (e.g., Krofcheck et al., 2017; Liang et al., 2017). The strength of LANDIS-II lies in its process-based approach to forecasting the interactive effects of climate, succession, and multiple disturbances (Lucash et al., 2018), and its ability to simulate succession as an emergent property of these processes and species' life history strategies (Scheller et al., 2007). The wildfire extension of LANDIS-II, Social-Climate Related Pyrogenic Processes and their Landscape Effects, SCRPPLE) emphasizes both the biophysical and social dimensions of fire, enabling simulation of fire ignitions, fire intensity, fuel-treatment effects, fire suppression, and prescribed fires (Scheller et al., 2019). However, process models like SCRPPLE do not always capture extreme, low-probability events, particularly in wet landscapes, unless large numbers of replicates are run. Improving the capacity for process models like LANDIS-II to capture extreme wildfire events requires improved forecasting of the spatial pattern of ignition probability, wildfire intensity, and communities most exposed to risk by improving representation of the underlying mechanisms that drive wildfire, notably climate, topography and climate. This will help us better understand why, and under what climate conditions, wildfire risk may increase or decrease in the future.

The goal of our workshops is to form a cohesive, interdisciplinary research team across the biophysical and social sciences (Figure 1) that will work at the nexus of wildfire science to:
1) synthesize our current understanding of extreme fire behavior based on existing wildfire databases, 2) isolate the current gaps in our understanding of the social and biophysical markers that contribute to extreme fire behavior and community risk, 3) develop a roadmap for improving representation of mechanisms that drive extreme wildfire behavior, and 4) integration LANDIS-II into HPC environments to run wildfire simulations in larger landscapes with higher resolution to capture extreme wildfire events.

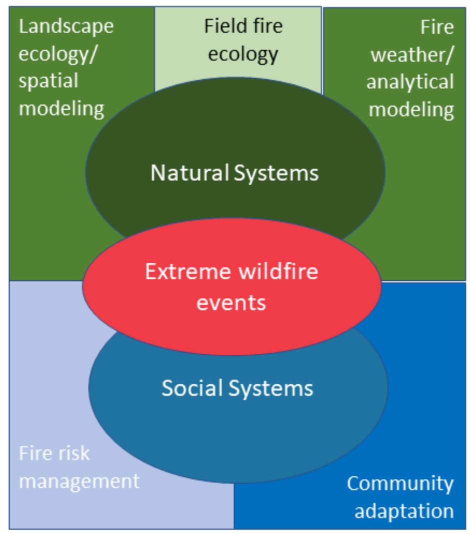

Figure 1. Our team of researchers is drawn from diverse areas of expertise, including natural (forest and fire ecology), and social systems (public policy)

We will demonstrate how these mechanisms can be applied in three unique landscapes: The Sierra Nevada of California, interior Alaska, and the Southern Appalachians. Each landscape has experienced, or is at risk of experiencing, extreme wildfire events. We have established projects and biophysical base layers developed for each landscape, allowing us to leverage existing data and ongoing community outreach efforts. Working across all three landscapes, we will develop consistent representations of mechanisms (albeit with local parameterization) that could be applied to any landscape across North America. For each landscape, we will demonstrate how these improved representations can be incorporated into forecasting engines, using the LANDIS-II model framework as a demonstration platform.

Proposed Activities

Stage 1: We will meet our stakeholders representing the biophysical modeling, field fire ecology, and social science community to understand the current gaps in our understanding of the social and biophysical markers that contribute to extreme fire events in an in-person workshop in Boulder, CO in the summer of 2024. We will synthesize our understanding of extreme fire behavior, identify data sources useful in identifying extreme fire events, identify gaps in understanding and modeling extreme fire behavior, and generate a comprehensive list of ways to address identified gaps. We will also work directly with ESIIL postdocs and Cyverse and Jetstream teams to facilitate the integration of LANDIS-II in HPC environments to run wildfire simulations in larger landscapes with higher resolution and to allow for an increase in the number of simulations to capture extreme wildfire events. **Stage 2:** We will create virtual breakout groups that meet for one hour every two months that focus on: 1) synthesizing our understanding of extreme fire behavior using existing data sources, and 2) identifying gaps in our understanding and modeling of extreme fire behavior, and 3) identifying ways to improve delivery of timely information to communities. **Stage 3:** At a workshop in Boulder, CO in the summer of 2025, we will collectively write a paper synthesizing our understanding of extreme fire behavior and potential social consequences. Also, we will draft a plan to submit proposals that will address gaps in forecasting extreme wildfire events and their social consequences. Finally, we will complete documentation that describes the integration and use of LANDIS-II in HPC environments.

Advancing DEI

The project leaders bring unique experience and history that advances DEI goals. Dr. Lucash has worked extensively with tribal organizations and with underrepresented students. Dr. Scheller has worked with tribal organizations and HBCUs, organizing summer programs for underrepresented students. Dr. Nowell is a community and organizational psychologist who specializes in issues of representation and inclusion in governance arrangements including issues of co-production and community and tribal representation in wildfire governance. Similarly, our list of participants has a long history of supporting underrepresented groups and/or are members of underrepresented groups themselves. The participants in our team are diverse with respect to 1) scientific discipline- social scientists (27%), biophysical sciences (73%)), field ecologists (27%), and modelers (47%), 2) career stage (40% considered recent graduates), 3) gender (47% women), and 4) underrepresentation based on race/sexual preference/veteran status (33%). We will devote a substantial portion (~ 20%) of each workshop to planning how we can incorporate DEI into fire science and environmental data science with a particular emphasis on reaching underrepresented students at our respective institutions and underrepresented stakeholders (e.g., tribal leaders). We will discuss and explore formulating a plan for diversifying the hiring of modeling PhD students (and hence, improving the postdoc and faculty pipeline); improved recruitment of underrepresented groups into government agencies; outreach to tribal communities in each of our three landscapes to assess institutional barriers.

Rationale for ESIIL support

A major limitation with increasing ecological modeling complexity is the need for higher-level computing resources (Shifley et al., 2017). The modeling component of this group utilizes the LANDIS-II landscape modeling framework that is currently being incorporated into the Cyverse and Jetstream environment. If granted, the group will work directly with ESIIL postdocs, education team, as well as the Cyverse and Jetstream teams, which will improve model integration and usability (via detailed support documentation) of LANDIS-II in HPC environments. This integration will allow users of LANDIS-II to run wildfire simulations in larger landscapes with higher resolution and allow for an increase in the number of simulations to capture extreme wildfire events, allowing for better estimates of outcome variability.

Collaborations with other ESIIL activities

Our group plans to work directly with ESIIL postdocs and the Cyverse and Jetstream teams to facilitate the integration of LANDIS-II in HPC environments and promote usability across the entire LANDIS-II community of 1,689 users (https://groups.google.com/g/landis-ii-users). We also plan to explore synergies with other working groups funded by ESIIL.

Anticipated IT Needs

We seek IT support for several crucial aspects of our working group. First, we would require secure and shared data management for input files and storage solutions to efficiently organize and run statistical analysis on our data assets with R. Additionally, we would need allocated High-Performance Computing (HPC) resources for scalability and flexibility in running LANDIS-II, a large-scale, high-resolution forest landscape model. We also seek technical support from ESIIL partners to facilitate the seamless integration of LANDIS-II, an open-source forest modeling framework created to run in a Windows environment, into local HPC systems. This support will enable us to harness the full potential of cutting-edge technology in our mission to advance scientific research and innovation of wildfire risk modeling of extreme events. All modules used within the forest landscape modeling framework will be hosted on the LANDIS-II Foundations github repository (https://github.com/LANDIS-II-Foundation). Any new tools developed through this working group, such as methods of HPC integration, will also be hosted within this repository. Due to the large storage needs, the LANDIS-II outputs from this workshop will be stored locally and can be made available upon request. Modeling results will be analyzed and published in a peer-reviewed journal.

Proposed Timetable

Format	Goal	Date	Meeting length
In person	Identify knowledge gaps. Integrate LANDIS-II into HPC environments	July 2024	4 days
Virtual	Synthesize current efforts addressing the key components lacking in wildfire modeling	Fall 2024	1 h meeting every 2 m
In person	Write a synthesis paper, outline future proposals and complete documentation	July 2025	5 days

Outcomes

We will collectively write a draft of a paper synthesizing our understanding of extreme fire behavior and potential social consequences. We will outline plans to submit proposals that will address gaps in forecasting extreme wildfire events and their social consequences. Finally, we will integrate LANDIS-II in HPC environments, providing a roadmap for other vegetation and wildfire models to run in HPC environments.

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