Forests in Flux: How Science Can Inform Policy

December 11th, 2019

Event Hosted by

The John Muir Institute of the Environment at UC Davis and the USDA California Climate Hub with the participation of the California Natural Resources Agency

Background

California, along with the rest of the western seaboard of North America, is experiencing large-scale and rapid changes to forest ecosystems. These changes are expected to have drastic impacts on the provision of ecosystem services that these forests provide, like clean water and carbon storage, as well as on human health and safety. Successful execution of solutions to mitigate and adapt to these changes is complex and requires extensive planning and foresight. To broaden understanding and enable adaptive management given ever-changing conditions facing western forests, the "Forests in Flux: How Science Can Inform Policy" event was organized with the aim of strengthening the dialog between policy/decision makers and scientists focused on forest related issues.

Event Organization

The Forests in Flux event was designed to bring together some of The West's (California, Oregon, Washington and British Columbia) leading scientists and state and local forest policy/decision makers. In total, the event, which took place on December 11, 2019, had over 80 people in attendance representing all states/provinces along the western seaboard from British Columbia to California. Of note, the States of California, Oregon and Washington and the Province of British Colombia were concurrently gathered as a part of a Forest and Climate Memorandum of Understanding (MOU) signed between the jurisdictions to discuss priorities. Attendees from the MOU contingent also attended the event. The event focused on seven forest science focal topics: Historical Wildfire, Cultural Burning, Fire impacts on Air Quality, Fire in the Wildland-Urban Interface, Forests and Water, Forest Mortality, and Forest Carbon. For each topic, one lab (one lead scientist and up to two collaborators) was selected to discuss policy and management related science issues and provide key take-home messages garnered through their research. In addition to the scientists from the highlighted labs, additional leading scientists throughout the West were invited to contribute their expertise informally.

Each highlighted lead scientist was invited to present a lightning talk of four minutes to introduce their lab, research and present their take home messages. In conjunction with these lightning talks, each lab was invited to display three posters to explain their key messages and supporting science. Following the lightning talks, the majority of the evening was an informal poster session and networking event designed to build and/or strengthen professional relationships between policy/decision makers and scientists, and enable a focused exchange of ideas on solutions to the West's forest management issues.

Highlighted Scientists

Focal Topic Area	Scientist	Affiliation
Historical Wildfire	*Alan Taylor (Lead)*	Pennsylvania State University
	Lucas Harris	Pennsylvania State University
Cultural Burning	*Don Hankins (Lead)*	Cal State University, Chico
Fire in the WUI	*Max Moritz (Lead)*	UC Cooperative Extension, UC Santa Barbara
	Van Butsic	UC Cooperative Extension, UC Berkeley
Fire Impact on Air Quality	*Allen Goldstein (Lead)*	UC Berkeley
	Kelley Barsanti	UC Riverside
	Rebecca Wernis	UC Berkeley
Forest and Water	*Roger Bales (Lead)*	UC Merced
	Martha Conklin	UC Merced
	Qin Ma	Mississippi State University
Forest Mortality	*Jodi Axelson (Lead)*	UC Cooperative Extension, UC Berkeley
	Lauren Cox	UC Berkeley
	Carmen Tubbesing	UC Berkeley
Forest Carbon	*Beverley Law (Lead)*	Oregon State University
	Polly Buotte	UC Berkeley
	Tara Hudiburg	University of Idaho

Event Synthesis

The following summary reflects the messages, results and conclusions delivered by each featured scientist during the event and how each topic relates to one another. However, taken together, these messages provide interrelated insights into the state of our knowledge on the latest in forest science and management. The take-home messages in the boxes below are the verbatim messages given on the posters by the invited labs. The narrative is paraphrasing all of the information provided by the posters and given verbally by the scientists at the event.

The Fire Deficit

Understanding the historical context of forest and wildfire conditions provides an opportunity to understand how divergent western forests currently are as a result of the past century's forest management, policies and climate change. Forests and fire have varied widely throughout history from both human intervention and changes in the climate. Consistently, however, fire frequency has tended to closely follow temperature (e.g., rising temperatures, corresponding with increased fire activity). Given this correlation, it is estimated that fire suppression efforts over the last 100 years has created a large "fire deficit". Given current temperature and based on historical patterns, in general we expect that western forests should be experiencing much more fire (with the exception of southern California). This fire deficit has resulted in altered forest structure and composition, and, consequently, artificially low fire emissions and air quality. Additionally, this fire deficit has resulted in up to 270% greater carbon stocks in our current forests than under historical conditions. This long history of fire suppression has especially increased the carbon in the "duff layer" or the bed of the forest floor. The carbon in the forest floor constitutes the majority of emissions during wildfires. When these carbon rich forests finally burn, burn severity has little influence on the overall total carbon emissions, because both low and high severity fires burn the large amount of carbon built up on the forest floor. This indicates that even low intensity prescribed burns will have a large impact on carbon emissions and that to return to historical forest conditions and fire regimes would require burning nearly 2/3 of our current carbon stocks. If "repaying" this fire deficit is a goal, then it will come at a cost in the form of more fire and smoke.

Take-home Message
Historical Wildfire:

- Fire activity has followed socioecological change in the Sierra Nevada, and fire exclusion since 1850 has caused a *fire deficit*. Modeling reference conditions can help guide management.
- Carbon storage increased but its spatial pattern changed due to fire suppression then wildfire. Wildfire emissions were high but did not vary by fire severity

Cultural Burning

Additionally, the West's forest ecosystems developed alongside historical cultural indigenous burning. In this way, our "historical natural" forest conditions and fire regimes can be considered a combination of indigenous burning and climate-driven influences. Cultural burning differs from current prescribed burning practices in that cultural burning is more nuanced in its co-benefit, outcome-driven, place-based management style, and requires specific burning seasons and fire intensities. Cultural burning projects are individually designed given a specific forest type and the desired co-beneficial outcomes, i.e., burning is explicitly designed not only to reduce fuels but also to promote biodiversity, maintain stream flows, and encourage regeneration of specific plant communities. To fulfill this multi-objective design, burning must be timed correctly with the season, in line with the ecosystem life cycle. Additionally, cultural burning tends to be more patchy or heterogeneous with some areas receiving high intensity and severity burns while others receive low intensity, long-lasting, smoldering burns. Cultural burning practices are not widely utilized by government agencies because practitioners with the required place-based knowledge to effectively carryout cultural burning often do not have the required federal and state certifications to plan and perform large-scale burning operations. Additionally, the need to diversify the intensity and duration of fire in cultural burns runs counter to air district burn windows, which encourage fast burning high intensity fires, to burn as much fuel in as short amount of time as weather conditions allow. Solutions to these issues could include modifications to state and federal requirements on burn boss and red card certifications to allow more indigenous cultural burning practitioners. Additionally, cultural burning could be reclassified as "natural," as it developed alongside our ecosystem. In this way, cultural burning could be treated differently for air quality considerations.

Take-home Message
Cultural Burning:

- California's fire-prone ecosystems evolved with Indigenous burning as a keystone process. This process mitigates climate variability, wildfire impacts, biodiversity declines, and supports fire-dependent cultures.

- Indigenous fire is place-based and can achieve a great range of beneficial outcomes

Fire in the Wildland Urban Interface

Fire has been and remains an essential process in our forested ecosystems. In recent years however, our fire deficit and our departure from a co-benefit driven fire regime, coupled with increased development of human population centers in forested areas, has resulted in catastrophic fire events that have killed numerous people and continue to threaten communities throughout the West. For this reason, it is necessary to understand how we can keep lives and property safe under increasing risk from wildfire.

Take-home Message
Protecting Communities:

- Where and how we build affects future fire activity AND future home losses
- New guidance for urban design and land use planning in the WUI is available (see poster "Building to Coexist with Fire: Community Risk Reduction Measures for New Development")

Human development drives many of the fires seen on the landscape, with proximity to a community being a strong predictor of fire frequency, making forests and other lands around communities more likely to burn than wilderness areas. Once a wildfire reaches a community, however, the fire stops being a forest management issue and becomes a product of planning, zoning and building codes. Building codes may help create fire resistance on the individual home level, but on the community level, planning and zoning influence the large-scale loss experienced. For example, higher home losses are consistently observed in lower housing density wildland urban interface (WUI) developments. A synthesis of new guidelines has been produced to help policy/decision makers reduce fire risk to communities. These guidelines combine landscape-level planning, separating communities from wildfire sources, housing density management, and infrastructure concerns. In this way, protecting lives and property from wildfire involves forest management, especially proximate to communities, but cannot only rest on the forest manager/policy maker and must include local planners, developers and elected officials.

Prescribed Fire and Air Quality

To protect lives and property, and bring forests back to health, one consistent tool identified is to introduce more and safer fire to the landscape through prescribed burning. As more fire is introduced to the forest, it is essential to consider the air quality impacts of this increase. The air quality implications of fire can vary widely depending on the intensity of the burn and fuels in which it occurs. Fires can range from a low intensity smoldering burn to a high intensity flaming fire, delivering different emissions and air quality implications. Typically, the hotter the fire, detrimental air quality impacts decrease, but greenhouse gas emissions increase. Dependent on the fuel source in which a fire burns, resultant air quality impacts differ. Terpenes are chemical compounds emitted from fires in large quantities that lead to ozone and particulate matter formation (both of which are deleterious to human health). Terpene emissions vary by fuel species (e.g. pine and fir tree, shrubs, grasses) and fuel component (e.g. canopies, forest floor, trunk and branches, dead down wood). When fires burn tree canopies, typically, high levels of terpenes are emitted. The fuels targeted by prescribed fires, e.g. forest floor and down dead wood, have lower terpene emissions and likely lower particulate matter formation in plumes. In general, to decrease the air quality impact from fire, prescriptions should minimize the smoldering phase of fire, should not allow large amounts of fuel to build on the forest floor and should consider the types of fuels that will be burned. However, more, hotter fires will increase climate-warming emissions. This climate warming could result in hotter burning wildfires reducing detrimental impacts to air quality from future fires on a per fuel burned basis. Confounding this guidance, recall from the previous cultural burning talk that to maximize burning intensity goes against cultural burning guidance which would call for varied intensity burns depending on the co-benefit outcome objective(s). This makes balancing air quality and ecosystem outcome objectives a complex task.

> **Take-home Message**
> **Air Quality and Prescribed Fire:**
>
> - Prescribed Fires Can Have Co-Benefits for Air Quality
> - Flaming Prescribed Fires Result in Better Air Quality Than Smoldering Fires

Forests and Water

Fire, however, is but one aspect of forest ecosystems that must be considered as we develop policy and decide on management strategies going forward. Water is one of the most critical resources that the West receives from forested ecosystems. Our current fire deficit, high amount of carbon on the landscape and warming climate has resulted in: 1) more water taken up by plants (and unavailable for other uses); 2) more precipitation in the form of rain instead of snow (less long-term storage of water in the form of snow disrupts the gradual provision of water supply to downstream rivers/reservoirs); and 3) less seasonal water storage and increased forest mortality. Forest management can play a role in mitigating the impact of some of these changes. For example, strategic reduction of excess biomass in forests can result in increased water availability for human use. Actions such as thinning of overstocked forest stands, up to 68% of the extent of the Sierra Nevada, from 3000-6000 feet in elevation, could provide additional available water to Californians equivalent to the capacities of Folsom Reservoir and Millerton Lake combined annually. That said, maintenance of biomass reduction projects is crucial over time. In the Sierra, fire or thinning impacts on available water typically last 5 to 15 years. This means that these treatments should be maintained on approximately a 15-year interval to maintain enhanced

> **Take-home Message**
> **Provision of Water:**
>
> - Thinning treatments can reduce forest water use, increasing runoff and benefitting downstream water users, and monetizing those benefits can help fund forest restoration
> - Wildfire generally reduces forest water use (evapotranspiration), and water use gradually increases as vegetation grows back after disturbance.
> - Mapping of water use by vegetation (evapotranspiration) provides predictions of drought-related resistance versus vulnerability to forest mortality

water availability. To develop and execute such complex repeated projects, new financing and implementation pathways can be developed, such as the Yuba County Resilience Bond. In addition to improving water available for human consumption, treatments will increase water available to the remaining trees, increasing their drought resilience. However, as droughts continue to increase in severity, we expect more forest mortality on the order of 15-20% tree death per degree Celsius (1.8 degree Fahrenheit) warming.

Forest Mortality

> **Take-home Message**
> **Forest Mortality:**
>
> - Understanding how bark beetle outbreaks drive mortality patterns and duration is essential to develop predictions of future tree mortality
> - Future forests will have fewer large pines, more small shade tolerant trees, and higher levels of large surface fuels
> - Combating tree die-off requires increasing the pace and scale of thinning and dead tree removal, but bioenergy isn't a silver bullet

Forest mortality has had a dramatic impact on The West's forest ecosystems and all of the ecosystem services these forests provide. Droughts and increasing temperatures in general have increased native beetle populations to epidemic levels resulting in 147 million dead trees in California across 9.7 million acres, or about 5% of all live tree biomass. This demonstrates one example of the vulnerability our forest ecosystems have to climate change. The extent and impact of forest mortality varies by elevation and latitude, with greater mortality seen in the southerly reaches along the western seaboard. Additionally, lower elevation pine forests die more quickly in response drought than higher elevation fir forests. The resulting excess of dead trees will build up on the forest floor, increasing fire risk and altering tree regeneration. In general, as temperatures increase and droughts exacerbate, we can expect fewer pines trees and more, smaller fir tree species, with increased quantities of fuels on the forest floor. This will most likely augment the fire prone status of forests, producing more high severity fires. Additionally, these changes will continue to alter our forest ecosystems in general, and the services they provide (water supply, biological diversity, flood control, etc.). One solution cited to combat the effects from increase in dead wood in the forest, is to utilize it in the form of bioenergy. Though this solution could produce nearly 14% of California's energy for one year, only 1/3 of the existing dead biomass meets minimum criteria for cost-effective bioenergy feedstock.

Forest Carbon

To stem the tide of even more forest die-off, western forests must work to regulate and minimize increasing temperature as both wildfires and forest mortality follow increasing temperatures. Western forests can play a large role in helping mitigate global climate change by maximizing carbon storage while balancing other ecosystem services. For example, prioritizing protection of current carbon stores, rather than enhancing sequestration, is critical to mitigating climate change, with the added benefit of preserving biodiversity and critical habitat. Once current stocks are stabilized and preserved, afforestation and reforestation (i.e., enhancing sequestration) efforts should occur where appropriate. However, the most effective way to increase carbon uptake is to restrict harvests and/or increase harvesting rotation lengths. This is because harvesting and wood products are the largest emitters of carbon in western forests. Though fire is often pointed to as the largest contributor to climate change from forests, 21st century fire CO_2 emissions in western forests are only 20% of wood product emissions and less than 5% of fossil fuel emissions. This is promising as fire is hard to control and is a natural process, while policy and management can influence harvesting, thus providing a powerful tool in the fight against climate change. Carbon storage, however, must be balanced with fire risk to communities, water availability, and forest health. Forest inventory and life cycle analysis-based estimates indicate that western forests are currently a net sink, but this sink is likely to decline as forest vulnerability to drought and fire is increasing across the West. Thus, preservation of current stocks is of critical importance, that can be bolstered by increased carbon uptake through changes to forestry practices (e.g., lengthened harvest cycles). The forests with the greatest carbon storage potential are the wet forests near the coast. Increased carbon stocks, however, must be balanced with other important factors such as fire risk and water availability. Continued improvements to greenhouse gas inventories are essential to track and monitor western states' climate related efforts, the effect those efforts are having on forest ecosystems, and the impact that climate change is having on these forests.

Take-home Message Carbon:

- Protecting temperate wet forests along the West Coast is critical for mitigating unwanted climate change effects and preserving biodiversity
- Effective climate mitigation strategies under future climate conditions are to preserve more forests with high carbon storage potential, lengthen harvest cycles, and reforest and afforest where appropriate
- 21st century CO_2 emissions fire in WA, OR, and CA are only 20% of wood product emissions and less than 5% of fossil fuel emissions

Posters

Changes in fire regimes, forest structure, and fire-climate relationships in the Sierra Nevada since 1600 CE

Alan H. Taylor[1]

[1] The Pennsylvania State University, University Park, PA

Fire activity has followed socioecological change in the Sierra Nevada, and fire exclusion since 1850 has caused a fire deficit. Modeling reference conditions can help guide management.

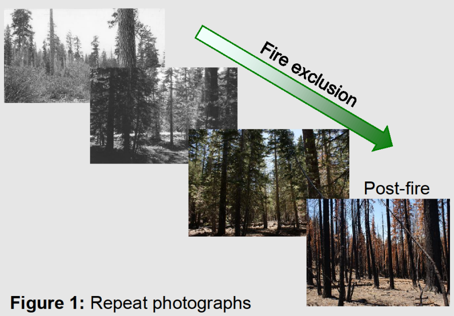

Figure 1: Repeat photographs illustrating fire exclusion and wildfire effects

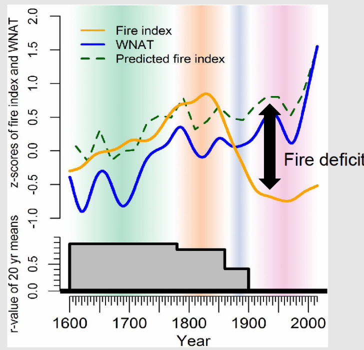

Figure 2: Correlation strength between summer temperature and fire index, and predicted fire based on summer temperature.

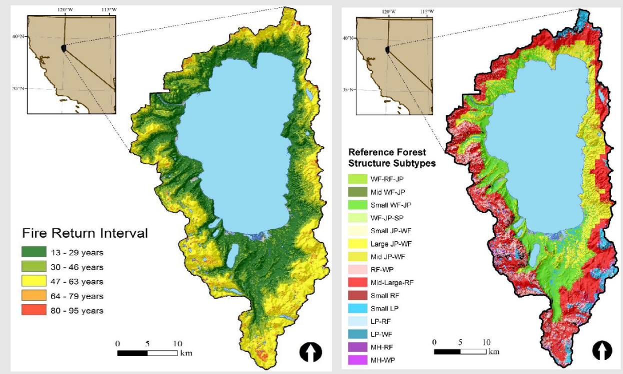

Figure 3: Presettlement fire return intervals and forest structure in the Lake Tahoe Basin.

Background and Rationale

- Forest conditions at the time of Euro-American settlement is a crucial point of refence
- Changes in fire activity have affected forest structure and fire hazard
- Tree ring analysis and modeling can produce maps of reference conditions

Main Results

- After 1850, a strong historical relationship between temperature and fire declined
- A fire deficit since 1850 has led to changes in forest structure and composition
- Maps of reference conditions show spatial variability in past fire regimes and forest structures

Conclusions

- Fire suppression has caused forests to deviate from historical conditions and created a fire deficit
- Spatial modeling of forest reference conditions can guide management in human-altered landscapes

Methods Outline

To evaluate the influence of humans and climate on fire regimes across the Sierra Nevada we used fire scar data from 29 sites. To identify reference forest structure, we used early forest survey and tree ring reconstruction data from 745 plots in unlogged forest. Fire scars in 226 trees in these same areas were used to identify spatial variation in fire regimes. A statistical model was also used to predict location of forest types and fire regimes across the landscape based on topography and climate.

References:

Taylor, A.H., Trouet, V., Skinner, C.N. and Stephens, S., 2016. Socioecological transitions trigger fire regime shifts and modulate fire–climate interactions in the Sierra Nevada, USA, 1600–2015 CE. *Proceedings of the National Academy of Sciences*, *113*(48), pp.13684-13689.

Taylor, A.H., Vandervlugt, A.M., Maxwell, R.S., Beaty, R.M., Airey, C. and Skinner, C.N., 2014. Changes in forest structure, fuels and potential fire behaviour since 1873 in the Lake Tahoe Basin, USA. *Applied Vegetation Science*, *17*(1), pp.17-31.

Changes in 20th century carbon storage and emissions after wildfire in an old-growth forest, Yosemite National Park

Lucas B. Harris[1], Andrew E. Scholl[2], Amanda B. Young[3], Becky L. Estes[4], Alan H. Taylor[1]

[1] The Pennsylvania State University, University Park, PA
[2]Kent State University, Kent, OH
[3]University of Alaska, Fairbanks, AK
[4]Pacific Southwest Region, USDA Forest Service, Eldorado National Forest, Placerville, CA

Carbon storage increased but its spatial pattern changed due to fire suppression then wildfire. Wildfire emissions were high but did not vary by fire severity.

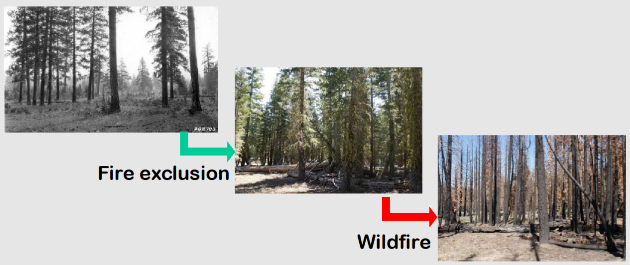

Figure 1: Repeat photographs from 1925, 2008 and 2013, illustrating fire exclusion and wildfire effects

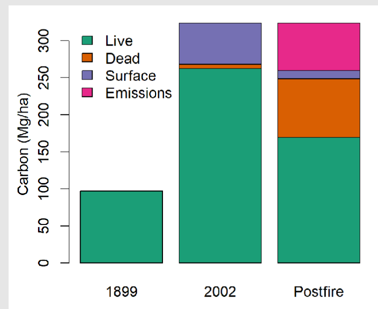

Figure 2: Change in carbon storage and emissions from 1899 to 2014

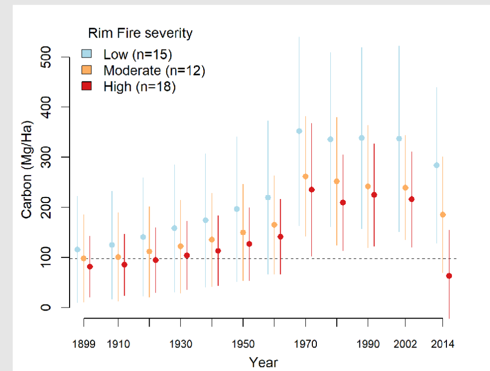

Figure 3: Carbon storage by fire severity class

Background and Rationale

- 20th century fire suppression and 21st century wildfire have influenced carbon storage
- Yet, field-based assessments of these effects are rare
- These effects have implications for future carbon storage and stability

Main Results

- Carbon storage increased by 270% over a century of fire exclusion
- Emissions from wildfire averaged 72 Mg/ha with 73 Mg/ha of dead trees
- The forest still held more carbon in 2014 than 1899, but its spatial pattern changed
- Trees > 1 m diameter hold 65% of live tree carbon

Conclusions

- High-carbon pockets of the landscape will need management focus
- Risk of forest loss in high severity zones
- Large-diameter trees are crucial to carbon storage

Methods Outline

Forest structure and surface fuels were measured in 85 field plots in 2002, and forest structure was reconstructed back to 1899 using tree ring methods. Allometric equations and tree rings were used to calculate aboveground carbon storage of live trees, snags and logs once per decade within each plot from 1899 to 2002. Carbon storage in live and dead trees, litter, duff and woody surface fuels were remeasured in 45 plots in 2014, one year following the Rim Fire.

References:
Harris, L.B., Scholl, A.E., Young, A.B., Estes, B.L., Taylor, A.H., 2019. Spatial and temporal dynamics of 20th century carbon storage and emissions after wildfire in an old-growth forest landscape. Forest Ecology and Management 449, 117461.

Contextualizing Indigenous fire practices as an ecological and cultural process

Don L. Hankins
California State University, Chico

California's fire-prone ecosystems evolved with Indigenous burning as a keystone process. This process mitigates climate variability, wildfire impacts, biodiversity declines, and supports fire-dependent cultures.

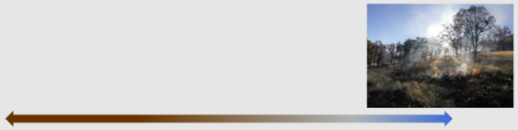

Figure 1. The extent of wildfires and the dry season is increasing, but Indigenous burning offers a tool to mitigate this trend (top photo Camp Fire 2018, Bottom photo cultural burn 2015)

Policy	What it Implies	Opportunity
Law of the Land (Indigenous)	Fire is a natural process, and the landscape speaks the need to burn	Policy reform at local, state, and federal levels should seek to recognize natural law
Convention on Biodiversity & UNDRIP (International)	Indigenous peoples have the right to steward their ancestral territories	Natural law is the basis of Indigenous stewardship, and is applicable to enable stewardship of ancestral territories
PL 93-638 / B 10 11 (Federal/State – Tribal)	Tribes, tribal organizations, and tribal individuals have the right to self-determination and stewardship within ancestral territory	Work with traditional cultural practitioners to establish stewardship landscapes and prioritization for shared stewardship
Clean Air Act – WRAP (Federal)	Indigenous fire can be treated as a natural and unregulated source of emissions	Utilize Indigenous partnerships to implement fire at a meaningful scale
Traditional Gathering Policy (Federal – Tribal in California)	Seeks to facilitate traditional management techniques on Forest Service and Bureau of Land Management Lands	Work with traditional cultural practitioners to establish landscape scale stewardship

Figure 2. Pertinent policies related to Indigenous fire and how policy could be used to support Indigenous fire

Figure 3. Map and images of current Indigenous burn project areas in California

General Community Type	Hypothetical Indigenous Fire Frequency	Approximate Annual Burn Extent (based on highest FRI)	J	F	M	A	M	J	J	A	S	O	N	D
Other Ecosystems	**	**							■	■	■	■		
Conifer Forests	5 – 15 years	500,000	■	■	■							■	■	■
Oak Woodland (savanna grassland)	2 – 5 years	2,000,000	■	■	■			■	■			■	■	■
Chaparral/Scrub Communities	10 – 50 years	460,000		■	■	■						■	■	■
Riparian Forest	4 – 15 years	2,500,000					■	■	■	■	■	■	■	
Floodplain (emergent and grassland)	3 – 10 years	600,000	■	■				■	■	■			■	■

(Month)

Figure 2. Conceptual example of Indigenous fire spatial and temporal variability. Frequency is derived from field observation. Extent is derived from Frequency and historic estimate of habitat coverage. Month is generalized from cultural knowledge of systems.

Ecocultural Fire Processes

- California's landscape has been stewarded with fire since time immemorial.
- Indigenous burning as a keystone process promotes biodiversity and wildfire mitigation.
- California Indigenous cultures are fire-dependent, and fire is a cultural responsibility.
- Indigenous fire practices are distinguished from other fire management in the context of traditional law, objectives, outcomes, and the right to burn (Eriksen & Hankins 2014).
- Indigenous fire can be treated as "natural" for air quality (WRAP 2005).

Why it Matters

- Fire is an inevitable part of vegetated ecosystems.
- Climate change is extending the dry season.
- The increase in wildfire area burned and frequency puts ecosystems and communities at risk.
- Global biodiversity is in decline
- Indigenous landscape stewardship has persisted through past climate events.
- Traditional cultural practitioners can provide knowledge to address ever-changing needs.

Take Home

- California's fire-prone ecosystems evolved with Indigenous fire through past environmental change.
- Indigenous fire is about getting the right fire in the right places at the right time.
- Indigenous fire is a critical tool in addressing wildfire, biodiversity declines, and climate adaptation needs.
- Existing policy is deficient in recognizing or supporting the role of Indigenous peoples use of fire.
- Indigenous burning could be supported through carbon marketing.

Background

Indigenous peoples of fire-prone regions have evolved and adapted with fire. Many Indigenous cultures are fire-dependent. Indigenous practices created cultural fire frequencies which shaped many ecosystems and created unique habitat types. The interdependent nature of Indigenous fire systems makes these systems some of the most integrated in the world. Across the American West there has been wider recognition of the role Indigenous peoples have played in shaping the environment with nuanced use of fire.

The uncoupling of Indigenous fire processes and environmental change began with European settlement, but is exacerbated by poor policy mandates and current climate change issues. Each person has a role in supporting Indigenous fire practices, find ways to support these efforts.

Collaborators & Partners:
California Indian Water Commission
Fire Learning Network – Indigenous Peoples Burning Network
Frank K. Lake, Amy Cardinal-Christianson, Christine Eriksen

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@Pyrogeographer

Comparative outcomes of Indigenous burning

Don L. Hankins
California State University- Chico

Indigenous fire is place-based, and can achieve a great range of beneficial outcomes.

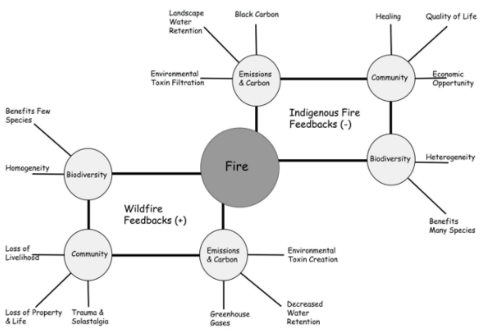

Figure 1. Conceptual feedback model of Indigenous fire compared to Wildfire.

	Indigenous	Agency/Public
Law	Traditional law based on natural law (i.e., wildfire can be reduced if people use fire)	Law is frequently counter to natural law (i.e., it is legally prohibitive to use fire)
Objective(s)	At least 73 reasons (e.g., create smoke to bring rain, maintain spring flow, ceremony)	Relatively few (e.g., hazard reduction or wildlife habitat improvement)
	Seasonally set for objectives	Based of models and staffing
Outcome(s)	Subsistence ability	Black acres
	Heterogeneity (e.g., species and habitat)	Less heterogeneity (e.g., edge)
	Nuanced response based on objectives	
Right to Burn	Ancestral responsibility and obligation	Certification or standards-based (e.g., NWCG, NFPA, etc.)
	Specialized knowledge and leadership	Career motivated with limited continuity
	Acquired through intergenerational learning	No requirement for ecological or cultural awareness to burn
	Ecological and cultural basis to burn	
Relative Cost & Reason	Low – Moderate	Moderate – High
	Family/Community-based and local	Personnel, equipment, travel to sites

Table 1. Comparison of Indigenous versus agency or public considerations in burning.

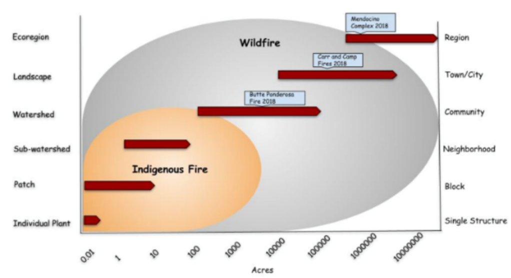

Figure 2. Social and ecological scaling differences between Indigenous fire and wildfire.

Distinguishing Indigenous Fire

- Rooted in natural law
- Objective-driven
- Typically fine grained
- Right to burn established by traditional law and extensive experience

Traditional Knowledge

- If fire is not utilized then wildfires will be extensive
- Place-specific
- Phenology-based
- Smoke benefits include:
  - condensation nuclei
  - Fumigation
  - environmental cooling
- Time-tested and adaptive to context feedbacks

Opportunity

- Provide funding to support existing Indigenous fire initiatives
- Identify shortcomings and streamline regulatory mechanisms to implement Indigenous fire.
- Identify research needs relevant to Indigenous communities and agencies

Supporting Studies

Lake, F.K.; M. Huffman; D.L. Hankins. Indigenous cultural burning and fire stewardship. In: Rego F.C.; P. Morgan; P. Fernandes; C. Hoffman. (2020) Fire science from chemistry to landscape management. Springer Nature.

Lake, F.K. ; A.C. Christianson. 2019. Indigenous fire stewardship. Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires.

Lake, F.K.; J. Parrotta; C.P. Giardina; I. Davidson-Hunt; Y. Uprety. 2018. Integration of Traditional and Western knowledge in forest landscape restoration. In: Mansourian, S., Parrotta, J., eds. Forest Landscape Restoration: Integrated approaches to support effective implementation. New York: Routledge: 198-226. Chapter 12.

David, A.T.; J.E. Asarian; F.K. Lake. 2018. Wildfire smoke cools summer river and stream water temperatures. Water Resources Research. 54(10): 7273-7290

Lake, F.K.; V. Wright; P. Morgan; M. McFadzen; D. McWethy; C. Stevens-Rumann. 2017. Returning fire to the land: celebrating traditional knowledge and fire. Journal of Forestry. 115(5): 343-353.

Long, J.W.; M.K. Anderson; L. Quinn-Davidson; R.W. Goode; F.K. Lake; C.N. Skinner. 2016. Restoring California black oak ecosystems to promote tribal values and wildlife. Gen. Tech. Rep. PSW GTR-252. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 11

Hankins, D.L., 2015. Restoring Indigenous Prescribed Fires to California Oak Woodlands: In Standiford, R.B.; K.L. Purcell tech. cords. 2015. Proceedings of the seventh California oak symposium: managing oak woodlands in a dynamic world. Gen. Tech. Rep. PSW-GTR-251. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 579 p.

Eriksen, C.E. and D.L. Hankins. 2015. Colonisation and Fire: Gendered Dimensions of Indigenous Fire Knowledge Retention and Revival. In A. Coles, L. Gray, and J. Momsen eds. *The Routledge Handbook of Gender and Development*, Chapter: 14, Publisher: Routledge, pp.129-137

Eriksen, C.E. and D.L. Hankins. 2014. The Retention, Revival and Subjugation of Indigenous Fire Knowledge through Agency Fire Fighting in Eastern Australia and California, USA. *Society and Natural Resources*.

Hankins, D.L. 2013. The effects of indigenous prescribed fire on riparian vegetation in central California. *Ecological Processes*. 2:24.

Emissions of Particulate Organic Compounds as a Function of Burning Conditions and Fuel Type

Rebecca Wernis[1,2], Coty Jen[3], Kelley Barsanti[4] and Allen Goldstein[1,2]
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Flaming Prescribed Fires Result in Better Air Quality Than Smoldering Fires

(a) Flaming fire **(b)** Smoke from a smoldering fire

Figure 1: Flaming (high combustion efficiency) fires emit much less particulate organic carbon and PAHs than smoldering (low combustion efficiency) fires per amount of fuel burned. Photos taken during a prescribed burn in the University of California-managed Blodgett Forest.

Grams of Pollutants per Kilogram of Fuel Burned vs Modified Combustion Efficiency

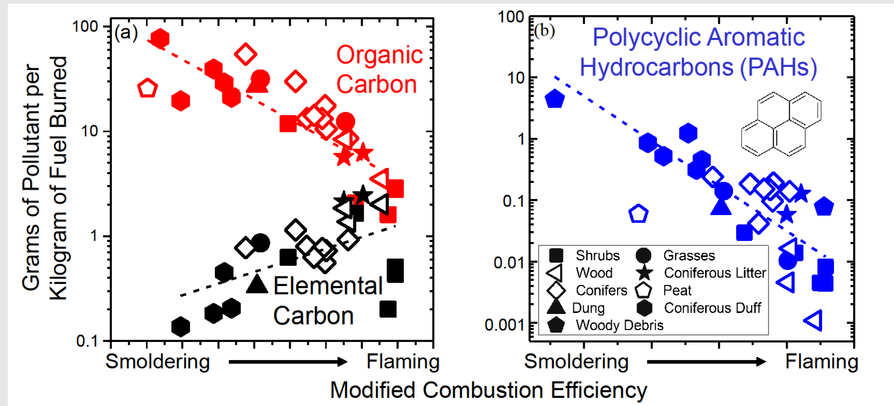

Figure 2: Emissions vary by fuel type and burning conditions for **(a)** organic carbon and elemental carbon and **(b)** specific chemicals such as PAHs. Exposure to PAHs has detrimental health impacts (Abdel-Shafy and Mansour, 2016). Figures from Jen et al., 2019.

Background and Rationale

- Prescribed fires are a critical forest management tool to reduce wildfire.
- Fire emissions including particles and PAHs are bad for human health.
- Particulate organic carbon cools the climate, while elemental carbon warms it.
- We study chemical composition and properties of fire emissions.
- Understanding of the variables that alter emissions is needed to improve air quality modeling.
- Controlled burning should be optimized to minimize emissions and reduce impacts on downwind communities and climate.

Main Results

- We quantified the dependence of emissions for particulate organic carbon, elemental carbon and specific organic chemicals on fuel type and burning conditions in a laboratory setting.
- Higher combustion efficiency led to lower emissions of organic carbon, including the toxic PAHs, as well as total particulate matter, but higher emissions of elemental carbon.
- Some fuels such as coniferous duff tend to smolder, releasing more organic carbon and PAHs than other fuel types.

Conclusions

- To reduce the regional air quality burden, prescribed burns should be designed to minimize smoldering by controlling fuel loads and types.
- Higher organic carbon and PAH emission factors can be expected from unmanaged forests than forests managed with regular controlled burns due to accumulation of fuels such as duff that burn less efficiently.
- However, climate warming from fire emissions of elemental carbon will increase with combustion efficiency.
- Emission factors used for modeling regional air quality should account for combustion efficiency.

Methods

For the FIREX (Fire Influence on Regional and Global Environments eXperiment) study, representative fuels characteristic of the western U.S. were burned and the emitted smoke collected on quartz fiber filters. The filters were analyzed for organic carbon, elemental carbon, and detailed chemical speciation. The data was used to calculate Modified Combustion Efficiency (MCE), useful for indicating the relative amounts of flaming versus smoldering combustion (Akagi et al., 2011).

$$MCE = \frac{\Delta CO_2}{\Delta CO_2 + \Delta CO}$$

FIREX was funded by NOAA. Coty Jen acknowledges support from the NSF AGS PRF.

Sources:
Jen, C. N., et al.: Speciated and total emission factors of particulate organics from burning western US wildland fuels and their dependence on combustion efficiency, Atmos. Chem. Phys., 19, 1013–1026, https://doi.org/10.5194/acp-19-1013-2019, 2019.
Akagi, S. K., et al.: Emission factors for open and domestic biomass burning for use in atmospheric models, Atmos. Chem. Phys., 11, 4039–4072, https://doi.org/10.5194/acp-11-4039-2011, 2011.
Abdel-Shafy, H.I., Mansour, M.S.M.: A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation, Egyptian Journal of Petroleum, 25, 1,107-123, https://doi.org/10.1016/j.ejpe.2015.03.011, 2016

Fingerprinting Fires to Improve Predictions of Air Pollutants

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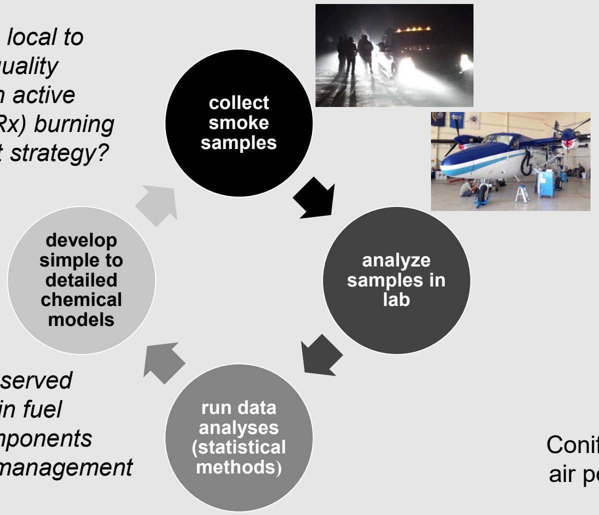
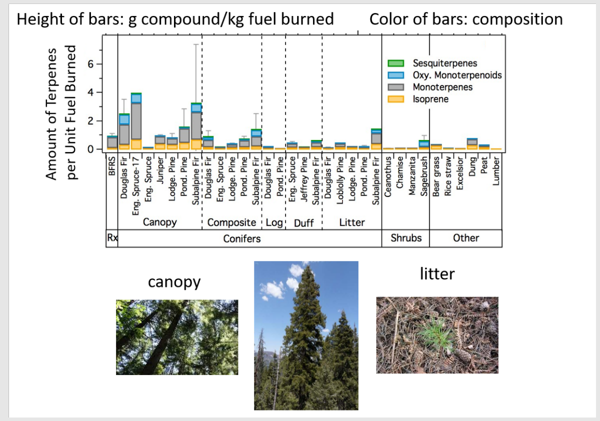
Prescribed Fires Can Have Co-Benefits for Air Quality

What are the local to regional air quality impacts of an active prescribed (Rx) burning management strategy?



How can observed differences in fuel species/components inform fuel management strategies?



Terpenes are chemical compounds emitted from fires in large quantities that lead to ozone and particulate matter formation; they are highly variable by fuel species and fuel component. This variability influences how much and where pollution is formed.

Conifers, particularly canopy fuels, emit the highest levels of terpenes, which can form air pollutants. Surface fuels emit lower levels of terpenes. Mapping the composition of emissions allows source fingerprinting and better air quality predictions.

Background and Rationale

-Particulate matter (PM) from wildfires leads to severe degradation of air quality
-PM is emitted from fires and formed in fire plumes
-PM emissions ("white/brown" + "black" carbon) are greater from wildfires than prescribed fires

g carbon/ kg fuel burned				
organic carbon (OC)	24.3	11.2	3.9	2.8
black carbon (BC)	(~3)	0.59	1.4	1.1

-In-plume/down-wind PM formation also may be lower for prescribed fires than wildfires

Main Results

- Reactive compound emissions, like terpenes shown here, are strongly dependent on fuel species and fuel component
- The amount and composition of emissions directly affects how much air pollution (particulate matter, PM) is formed in fire plumes
- Fuel components targeted in prescribed burns have lower terpene emissions, and likely lower in-plume PM formation

Conclusions

- Fuels species and fuel components have unique chemical fingerprints
- "Fingerprints" can be used to identify fuels and link specific fuels with adverse air quality effects
- Models need to include this diversity in emissions as a function of fuel type and fuel component to evaluate co-benefits of prescribed fires for fuels reduction and air quality mitigation

Methods Outline

Smoke samples were collected onto dual-bed absorbent cartridges and then analyzed in lab using two-dimensional gas chromatography with time-of-flight mass spectrometry. Data analysis proceeded using traditional and statistical approaches. Gas phase chemical mechanisms were developed using the SAPRC model and published data. Pollutant predictions rely on a range of chemical models with varying complexity.

Acknowledgements
Funding: NOAA AC4 NA16OAR4310103, NA17OAR4310007, NSF ATM 1753364
FIREX-AQ: Goldstein Group UCB, Steve Brown NOAA, Scott Herdon Aerodyne

References
[1] Liu, X., Huey, G.* et al., 2017. Airborne measurements of western US wildfire emissions: Comparison with prescribed burning and air quality implications. *J. Geophysical Research*
[2]Hatch, L., Barsanti, K.* et al., 2019. Highly speciated measurements of terpenoids emitted from laboratory and mixed-conifer forest prescribed fire. *Environmental Science & Technology*

Building to Coexist with Fire: Community Risk Reduction Measures for New Development

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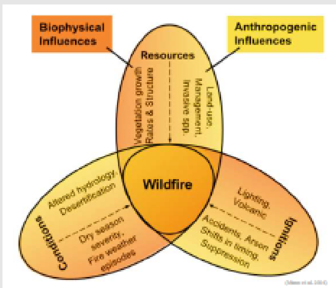
Where and how we build affects future fire activity AND future home losses: New guidance for urban design and land use planning in the WUI



Fire probabilities & losses are driven by biophysical & anthropogenic factors!

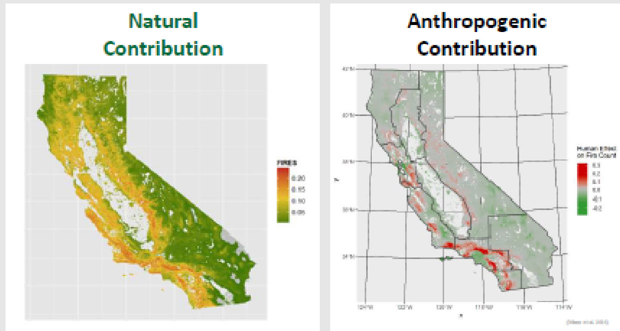


Figure 2: Influence of human development on fire activity varies spatially and is as important as biophysical variables in many locations.

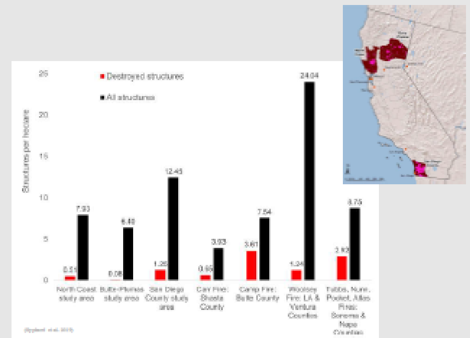


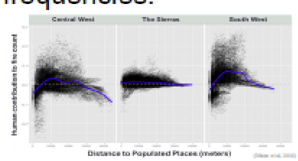
Figure 3: Home losses are consistently observed in lower housing density parts of the wildland-urban interface (WUI).

Background and Rationale

- Climate change is making many environments more fire-prone.
- WUI expansion changes ignition & suppression patterns, as well as increasing home exposure.
- There is much published & professional knowledge about risk community reduction not yet utilized in land use planning.

Main Results

- At landscape scale, housing density has predictable effect on fire frequencies.



- At community scale, siting & design of neighborhoods is crucial for risk reduction.

Conclusions

- Synthesis of research & professional experience from planners & fire professionals reveals under-appreciated role of development decisions.
- Better/stronger guidance on where & how we build must inform climate change adaptation & reduction of future losses in communities.

Community Risk Reduction Measures

Design context	Action	Scale	Goal
landscape setting of wildfire hazard	engage in strategic planning much earlier	community and subdivision	include risk reduction measures before other considerations finalized
	use hazard maps	community location	concentrate in least hazardous areas
	use major landscape features	community location	buffer against oncoming wildfires
separation from wildfire source	use nonflammable amenities in design	subdivision layout	maximize defensible space
	employ safe setbacks on slopes	subdivision layout	maximize defensible space
	concentrate along inner side of roadway	subdivision layout	maximize defensible space
density management	cluster with other homes	subdivision layout	reduce collective exposure
infrastructure concerns	harden public facilities and refuges	subdivision layout	safeguard vulnerable populations; provide fallback for worst-case conditions
	locate power lines underground	subdivision layout	reduce ignition potential
	augment water requirements	subdivision layout	ensure redundant supplies; employ exterior sprinklers

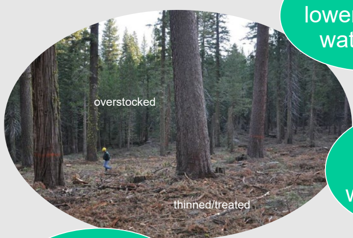
Moritz Lab

LUC LAB
Researching Land Use & Land Use Change

Forest Restoration: A Water-Resources Perspective

Roger Bales[1], Martha Conklin[1] and Qin (Christine) Ma[1,2]
[1]Sierra Nevada Research Institute, University of California, Merced
[2]Department of Forestry, Mississippi State University

Thinning treatments can reduce forest water use, increasing runoff and benefitting downstream water users, and monetizing those benefits can help fund forest restoration.



Thinning lowers forest water use

Water use increases with regrowth

Wildfire has water-quality & quantity impacts

Forests are at a tipping point, affecting water security & requiring large-scale intervention

Engaging water sector to help increase the pace & scale of forest restoration requires a whole-watershed, multi-benefit, participatory framework

Framing

- **Fire suppression**
- More biomass: overstocked forests
- **Warmer climate**
- Rain instead of snow & earlier snowmelt

Challenge

- More wildfire & More water use by forest
- Less water storage in headwater forests & less seasonal storage behind dams

Solution

- **Reduce biomass density**: drought resiliency, lower wildfire, better water quality, and more runoff, carbon sequestration, health & jobs
- **Develop financing & implementation pathways**
- **Enhance groundwater** recharge & storage

Activities

- Establish multi-benefit framework: Verify water-balance & carbon-balance outcomes, establish other benefits
- Communicate & engage, forge partnerships, develop risk-sharing mechanisms
- Empower trusted brokers & champions: State, NGO, finance, local, UC

Background and Rationale

Water-supply & hydropower providers benefit from fuels treatments: more water, lower fire & erosion risks.

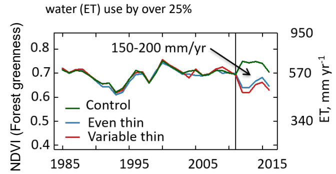
Changes in runoff from forest treatments are site specific, highly variable & seldom measured accurately.

Much, but not all, mountain forest terrain can be thinned and provide downstream benefits.

Water quantity benefits

Stanislaus-Tuolumne Experimental Forest: Variable Thinning Project, 2011, central Sierra Nevada

Basal-area decrease of 40-50% reduced forest water (ET) use by over 25%



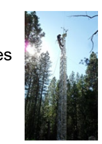
Conclusions

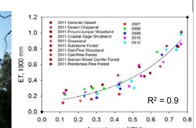
Forest water use is superior to runoff estimates from paired-catchment studies as a metric for water benefits of forest treatments.

Our evapotranspiration modeling approach provides robust projections & verification of water benefits from thinning.

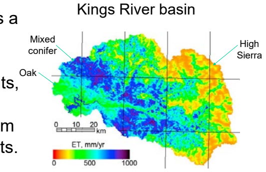
Methods Outline

Annual evapotranspiration (ET) measured at index sites is highly correlated with satellite greenness (NDVI). This relationship is used to map evapotranspiration across the landscape. Medium-intensity wildfire is a proxy for the amount of biomass removed from forest-restoration treatments, providing an index of potential water benefits from widespread fuels treatments.





Kings River basin



Acknowledgements
-NSF, Univ. California, USDA
-Mike Goulden (UCI)

Forest Disturbance: Wildfire and Management Effects on Water Balance

Qin (Christine) Ma[1,2], Roger Bales[1], and Martha Conklin[1]
[1]Sierra Nevada Research Institute, University of California, Merced
[2]Department of Forestry, Mississippi State University

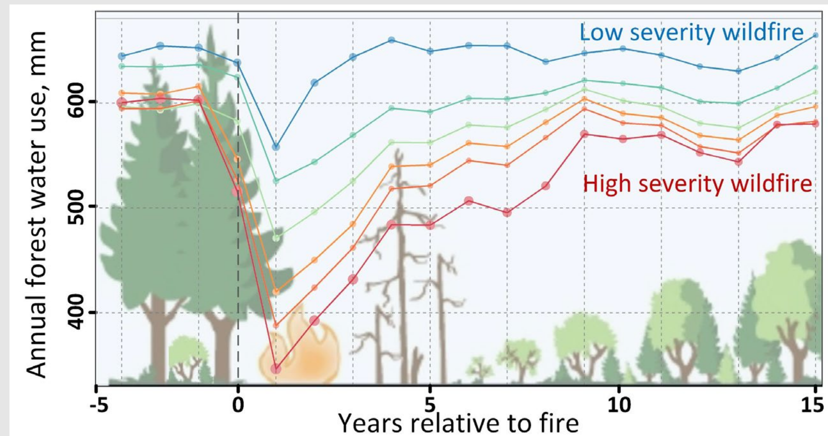
Wildfire generally reduces forest water use (evapotranspiration), and water use gradually increases as vegetation grows back after disturbance.

Wildfire lowers forest water use

Forest water use increases with regrowth

Satellites + site observations capture water use changes

Forest thinning to reduce fuels also reduces forest water use – similar to medium-intensity wildfire.



Background and Rationale

Reduction in forest water use from wildfire or treatments is highly variable over the landscape.

Historical wildfires indicate potential effects of fuel treatments on water use.

Basal-area reduction by medium-intensity wildfire approximates forest-restoration treatments.

Main Results

Water-use reduction in first year after wildfire averaged 80-200 thousand acre-ft/yr across Sierra.

Thinning 68% of Sierra forest, mainly overstocked areas at elevation 3000-6000 ft, could reduce average forest water use by amount equivalent to storage capacity behind Folsom plus Friant Dams.

Conclusions

Wildfire effects on forest water use last 5-15 years, or more.

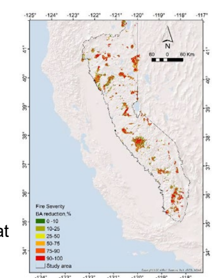
Realizing water (and other) benefits will require sustained thinning, on average every 15 yr.

Methods Outline

Wildfire effect on water use is estimated as annual evapotranspiration changes from pre- to post-fire, using satellites + site observation method.

Analyze all wildfires over 1000 ac in size for period 1985-present (available Landsat data)

Management effect on water balance is simulated from wildfires at various severities in 1985-2015 period over Sierra, providing a prediction on potential water benefits from widespread fuel treatments.



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-NSF, Univ. California, USDA
-Mike Goulden (UCI), Joe Rungee (UC Merced), Brandon Collins (UC Berkeley)

Forest Resilience: Mapping Tree Mortality and Drought Vulnerability

, Martha Conklin[1] Roger Bales[1]and Qin (Christine) Ma[1,2]
[1]Sierra Nevada Research Institute, University of California, Merced
[2]Department of Forestry, Mississippi State University

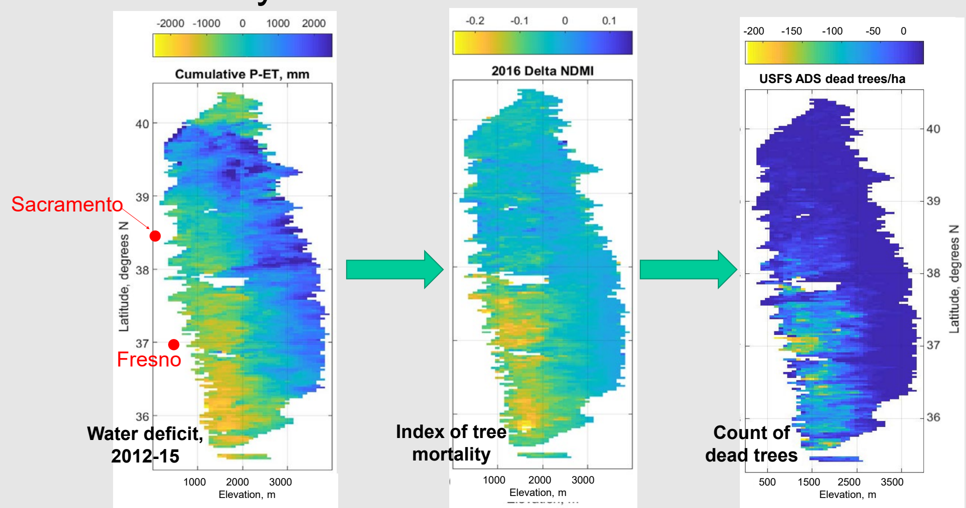
Mapping of water use by vegetation (evapotranspiration) provides predictions of drought-related resistance versus vulnerability to forest mortality.

Satellite data match aerial survey of dead trees

Satellite index of mortality correlated with P – ET

We can project P – ET for future droughts

The difference between precipitation & evapotranspiration (P – ET) is correlated with post-drought tree mortality.



Background and Rationale

The 2012-15 Calif. drought resulted in over 200 million trees suffering mortality.

Resilient forests have subsurface water storage to sustain water use during dry periods.

Water stress results when annual water demand by the forest exceeds annual precipitation plus water available in storage.

Main Results

Roots can draw water from as deep as 5-15 m down, providing historical drought resilience.

Hot drought of 2012-15 exceeded safety margin, due to less precipitation & higher water demand by trees.

Overstocked forests also key factor in drought stress.

Conclusions

Combination of dense vegetation, prolonged drought and warmer temperatures is not sustainable.

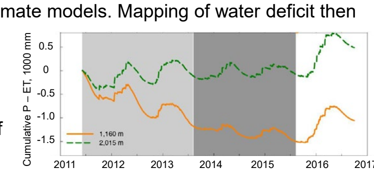
Project 15-20% increase in tree death for each additional °C of warming.

Areas vulnerable to drought stress are projected to have more forest mortality in the future.

Methods Outline

Precipitation is from the gridded data, and evapotranspiration from scaling of eddy-covariance flux tower data using Landsat NDVI. Water deficit for the 2012-16 drought is the cumulative drawdown of subsurface water storage, calculated from P – ET deficit, and verified with subsurface measurements.

For future droughts, projections of cumulative P – ET deficit can come from historical precipitation data, with temperature projected from climate models. Mapping of water deficit then indicates more-vulnerable areas, with negative values correlated with magnitude of tree mortality.



Acknowledgements
-NSF, Univ. California, USDA
-Mike Goulden (UCI), Toby O'Geen (UCD)

Massive Tree Mortality in the Sierra Nevada

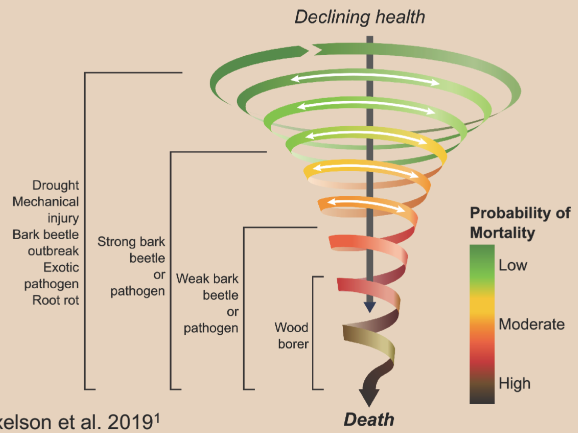
Jodi N. Axelson[1,2], Lauren E. Cox[1] and Carmen L. Tubbesing[1]

[1] University of California, Berkeley

[2] University of California Agriculture and Natural Resources

CAUSES

Understanding how bark beetle outbreaks drive mortality patterns and duration is essential to develop predictions of future tree mortality



Axelson et al. 2019[1]

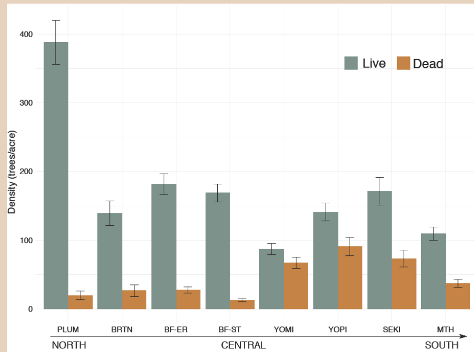


Figure 1: Total live and dead tree density in 2018. Black error bars show variability within each site.

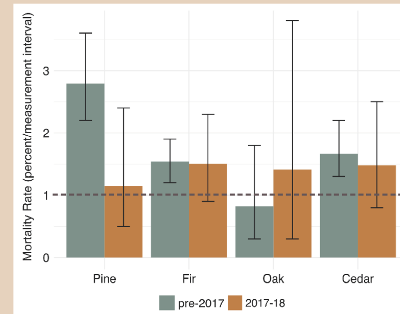


Figure 2: Mortality rate by taxonomic groups. Dashed line shows background mortality rate; black error bars show variability within a group.

Background

- The California drought (2012-15) included historic dryness and warmth resulting in over 147 million dead trees across 9.7 million acres on federal, state, and private land[2]
- This revealed the vulnerability of large portions of California's forest to novel conditions
- Massive tree mortality jeopardizes vital ecosystem services – understanding the drivers of mortality, ecosystem dynamics and management challenges associated with this event is of critical importance

Results

- A strong north to south gradient in mortality was present (Fig. 1) with significant contributions by native bark beetles
- At lower elevations pine bark beetles were significant drivers of mortality[3,4] while at our higher elevation sites fir engraver was a leading damage agent
- Mortality rates demonstrate how pine bark beetles respond very quickly to drought conditions killing pines early in the drought, while fir engraver populations gradually build and kill true firs over a prolonged period (Fig. 2)

Research to Extension

- In 2018, we began the *Tree Mortality Data Collection Network* to bring together the many scientists and agencies conducting field and remote-sensing studies across the Sierra Nevada
- With this network we translate our science into dialogue by hosting in-person events and putting our results into the hands of forest decision-makers and planners – this is **critical** to inform science-based policy in California

Our drought mortality study in the Sierra Nevada spans 285 miles and occupy five ownership categories

References

[1] Axelson, J., Battles, J., Das, A., van Mantgem, P. 2019. Coming to terms wit the new normal: Forest resilience & Mortality in the Sierra Nevada. Fremontia, 47: 50-56.

[2] [USDA] United States Department of Agriculture. 2019. Survey finds 18 million trees died in 2018. February 11 2019.

[3] Fettig, C., Mortenson, L., Bulaon, B., Foulk, P. 2019. Tree mortality following drought in the central and southern Sierra Nevada, U.S. Forest Ecology and Management, 432:164-178.

[4] Stephenson, N., Das, A., Ampersee, N., Bulaon, B., Yee, J. 2019. Which trees die during drought? The key role of insect host-tree selection. Journal of Ecology, 107: 2383-2401.

Acknowledgements

Collaborators: John Battles, Susan Kocher and participating scientists and stakeholders in the Tree Mortality Data Collection Network

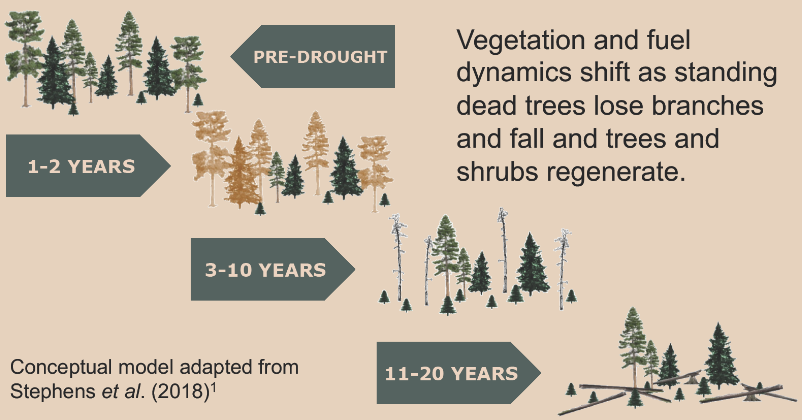
Funding: CalFire, National Park Service, UCANR, USFS Region 5

Massive Tree Mortality in the Sierra Nevada

Lauren E. Cox[1], Carmen L. Tubbesing[1], and Jodi N. Axelson[1,2]
[1] University of California, Berkeley
[2] University of California Agriculture and Natural Resources

EFFECTS

Future forests will have fewer large pines, more small shade tolerant trees, and higher levels of large surface fuels.



Vegetation and fuel dynamics shift as standing dead trees lose branches and fall and trees and shrubs regenerate.

Conceptual model adapted from Stephens *et al.* (2018)[1]

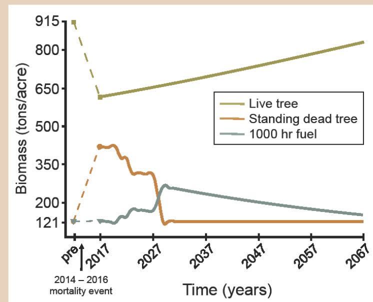


Figure 1: Model of biomass dynamics at Sequoia National Park after mortality event (diagram provided by John Battles).

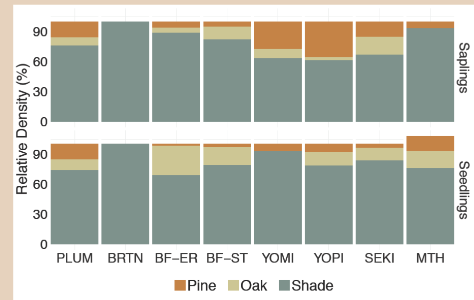


Figure 2: Forest regeneration in 2018 after drought-related mortality in Sierra Nevada mixed-conifer forests. Sites represent a latitudinal gradient arranged from north to south.

Background

- Disturbances alter the composition and structure of forests and have long-term impacts on future forest health and function
- The presence of millions of dead trees throughout a landscape alters biomass dynamics over time, and may compromise future forest resilience (Fig. 1)
- Understanding regeneration patterns and changing fuel dynamics is essential for projecting future forest conditions

Results

- As standing dead trees fall, large surface fuels will increase along with risk of severe fires (Fig. 1)
- Tree regeneration in both sapling and seedling classes is dominated by shade-tolerant species (Fig. 2), such as true fir and incense cedar
- Recent mortality has shifted species composition from pines to hardwoods and shade tolerant conifers, which could affect forest resistance and resilience to future disturbances and the capacity to adapt to a changing climate[2]

Results

- Disproportionate loss of large trees, especially pines, impacts wildlife habitat[3] and resilience to wildfires[1] and other future disturbances (Fig. 3)

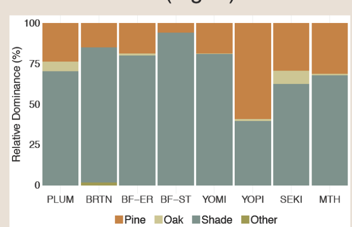


Figure 3: Relative dominance of recently dead trees (those that died during 2012-15 drought) in 2018.

Methods

- Established and monitored a network of eight sites along a latitudinal gradient throughout the Sierra Nevada mixed-conifer forest from 2017–2019
- Each site has between 29 and 36 fixed-radius plots
- Data is collected for overstory conditions, tree fall rates, fuel dynamics, tree regeneration, and shrub coverage

References

[1] Stephens, S.L., Collins, B.M., Fettig, C.J., et al. 2018. Drought, tree mortality, and wildfire in forests adapted to frequent fire. Bioscience, 68: 77–88.
[2] Young, D.J.N., Meyer, M., Estes, B., et al., 2019. Forest recovery following extreme drought in California, USA: natural patterns and effects of pre-drought management. Ecological Applications,13:e02002.
[3] Jones, G.M., Keane, J.J., Gutierrez, R.J., Peery, M.Z., 2018. Declining old-forest species as a legacy of large trees lost. Diversity and Distributions, 24: 341–351.

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Massive Tree Mortality in the Sierra Nevada

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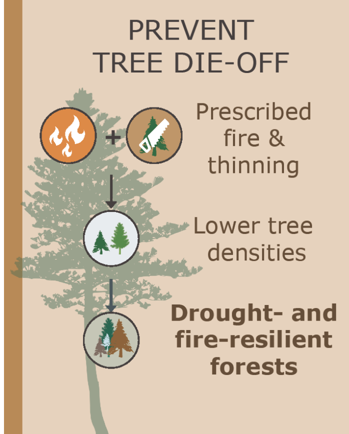
[2] University of California Agriculture and Natural Resources

SOLUTIONS

Combating tree die-off requires increasing the pace and scale of thinning and dead tree removal, but bioenergy isn't a silver bullet.



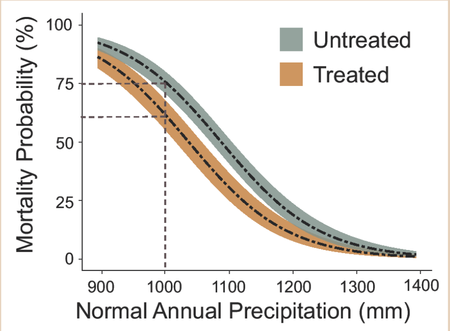


Figure 1. Treatment effects on ponderosa pine mortality. Figure adapted from Restaino et al. 2019[1] and was provided by Derek Young, UC Davis.

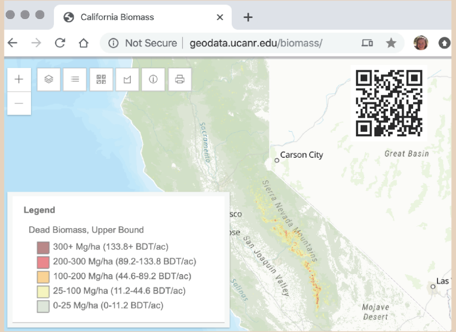


Figure 2. Biomass web tool developed for stakeholders interested in tree mortality mitigation or biomass energy site scouting.

Background

- In forests at risk of future drought-triggered die-off, thinning or prescribed fire that reduces competition and crowding can increase drought survival (Fig. 1)
- Where die-off has already occurred, selective removal of dead trees can reduce fire risk
- State plans for mitigation include biomass energy
- Planning tree-removal efforts, especially those that use the removed biomass for energy, require detailed mapping of dead and live biomass

Results

- The die-off created about 95 million tons of wood in dead trees, or about 5% of pre-drought live tree biomass[2]. Dead wood in any area of CA can be viewed in our interactive web tool (Fig. 2)
- Less than 1/3 of biomass meets minimum constraints for cost-effective bioenergy feedstock[2]

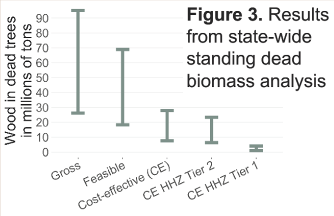


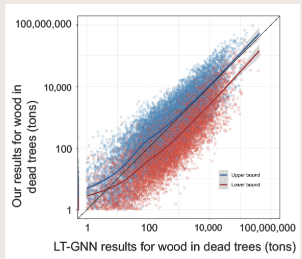
Figure 3. Results from state-wide standing dead biomass analysis

Conclusions

- Harvesting dead trees for bioenergy feedstocks is not a comprehensive solution for disposing of the majority of recently dead trees in CA, including in areas of highest priority to the state of California (High Hazard Zones)
- Nevertheless, harvestable biomass could produce a substantial quantity of electricity: our estimate of state-wide "cost-effective" standing dead biomass is equivalent to roughly 14% of one year of California's in-state electricity generation

Validation

- We compared our biomass estimates to independent LT-GNN results[3]
- Our upper estimates match LT-GNN results on average, but can be calculated sooner after die-off



References

[1] Restaino, C. M., Young, D. J. N., Estes, B., Gross, S., Wuenschel, A., Meyer, M. Safford, H. . 2019. Forest structure and climate mediate drought-induced tree mortality in forests of the Sierra Nevada, USA. Ecological Applications, 29: 1–14.
[2] Tubbesing, C.L., York, R. A., Stephens, S. L., Battles, J. J. *In Review*. Characterization of the woody biomass feedstock potential resulting from California's drought. Scientific Reports.
[3] Battles, J. J., Bell, D. M, Kennedy, R. E., Saah, David S., Collins, Brandon M., York, Robert A., Sanders, John E. 2018. Innovations in Measuring and Managing Forest Carbon Stocks in California. California's Fourth Climate Change Assessment, CEC-500-2013-058.

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How Do We Maximize Forest Carbon Storage?

Beverly Law[1], Tara Hudiburg[2], Polly Buotte[3], Logan Berner[4]
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[2]University of Idaho, [3] UC-Berkeley, [4] Northern Arizona University

Effective climate mitigation strategies under future climate conditions are to preserve more forests with high carbon storage potential, lengthen harvest cycles, and reforest and afforest where appropriate

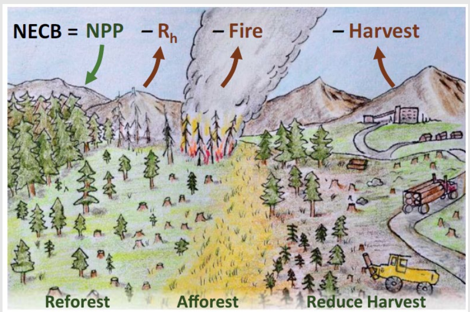

Figure 1. Net Ecosystem Carbon Balance (NECB) should be monitored and accurately quantified

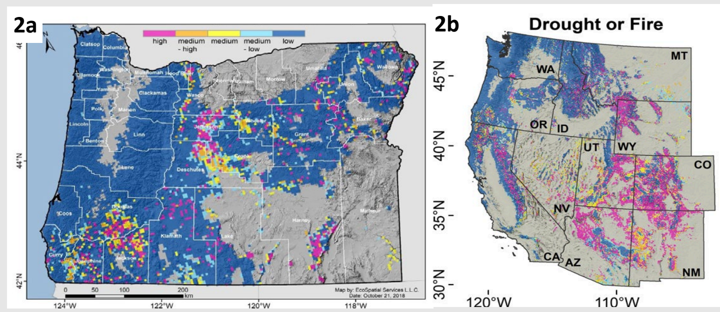

Figure 2: Vulnerability to mortality from drought or fire by 2050 in (a) Oregon and (b) the western US.

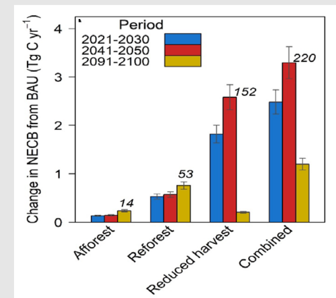

Figure 3: Effectiveness of future change in NECB with mitigation strategies compared to BAU management. Numbers over bars are cumulative change in NECB from 2015-2100.

Background and Rationale

- Nature-based climate solutions for reducing land-use emissions are essential
- Feasible land use strategies under future forest conditions need to be assessed for effectiveness
- Results can aid policy and management decisions

Main Results

- Forests with the highest potential to mitigate climate change are in western portion of the PNW
- Restricting harvest and longer harvest cycles can increase forest carbon uptake the most by 2100, followed by reforestation and afforestation

Conclusions

- Reducing harvest, longer rotations significantly increase C sequestration

Policies options:

- Create incentives for landowners to preserve and restore forest carbon
- Create preserves on public lands, which also protects watersheds and biodiversity
- CCC for carbon monitoring

Methods Outline

- Quantify net ecosystem carbon balance under current and future climate conditions
- Assess vulnerability to mortality from drought or fire under future climate and atmospheric CO_2
- Apply strategies to areas that have low future vulnerability and can support forests in the future and quantify change in forest carbon balance
- Life-cycle assessment to track carbon emissions associated with harvest, including long- and short-lived product decay, combustion of residues, recycling and land-fill decomposition.

Acknowledgements
Collaborators: Mark Harmon, Samuel Levis, David Rupp, Jeff Stenzel Phillip Mote.
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Computing: NCAR Computational and Information Systems Lab

Maximizing Forest Carbon Storage and Biodiversity

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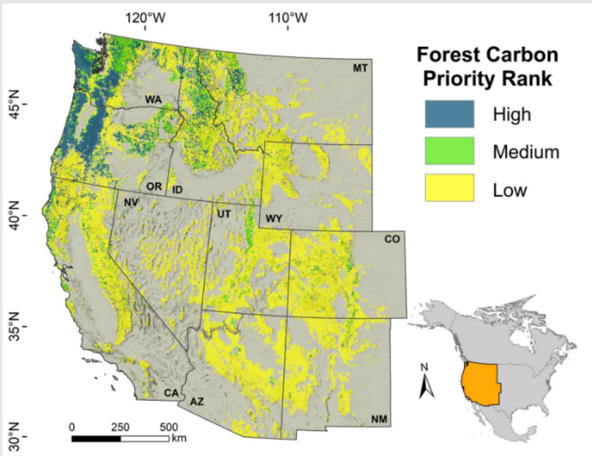
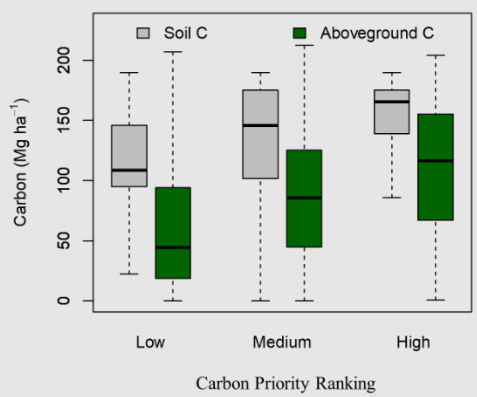
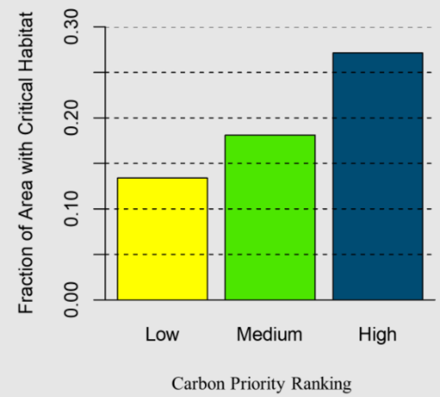
[2]Oregon State University

Protecting temperate wet forests along the West Coast is critical for mitigating unwanted climate change effects and preserving biodiversity







Buotte et al. 2019. *Ecological Applications*

Background and Rationale

- Forest vulnerability to drought and fire is increasing across the western US
- Forests management can contribute to climate change mitigation and the preservation of biodiversity
- Modeling can help prioritize forests for preservation

Main Results

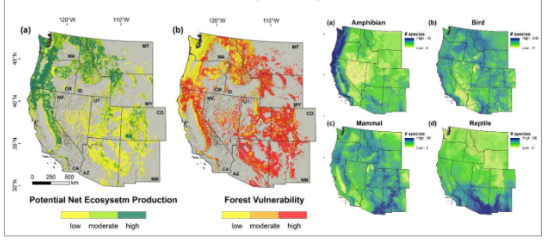
- Forests with the greatest potential to store carbon through 2100 are along the West Coast
- These forests contain high species richness and high area of critical habitat
- Forests with high carbon storage potential but higher vulnerability also support high biodiversity

Conclusions

- Protecting wet forests along the West Coast is critical for climate change mitigation and biodiversity preservation
- Protecting forests with frequent disturbance regimes (e.g. Klamath region) is also critical for sustaining biodiversity

Methods

- potential net ecosystem productivity
  - Community Land Model simulation with no harvest
- forest vulnerability to drought and fire
  - Buotte et al. 2019. *Global Change Biology*
- species richness
  - USGS National Gap Analysis Program 2018



Collaborators: Tara Hudiburg, Samuel Levis, Logan Berner, David Rupp, Phil Mote
Funding: USDA NIFA (2013-67003-20652, 2014-67003-22065, and 2014-35100-22066), US DOE (DE-SC0012194)
Computing: NCAR Computational and Information Systems Laboratory, NSF

Meeting GHG reduction targets requires accounting for all forest sector emissions

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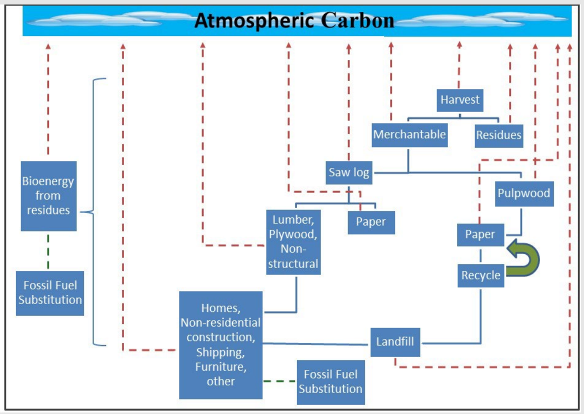
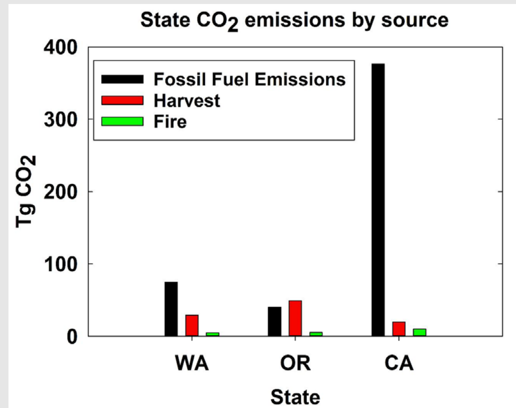
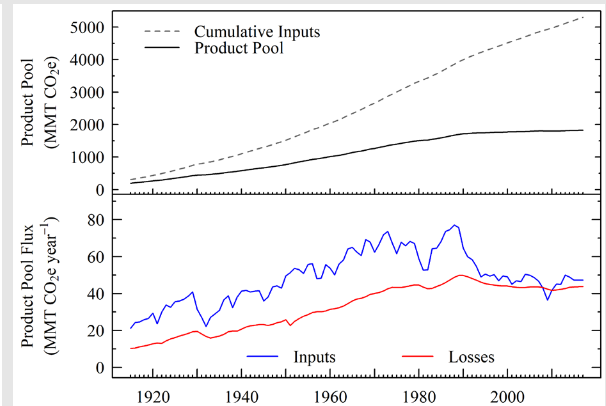
21[st] century CO_2 emissions fire in WA, OR, and CA are only 20% of wood product emissions and less than 5% of fossil fuel emissions.







Background and Rationale

- Wood product sector emissions are currently underestimated
- IPCC and state guidelines need to be improved
- GHG reduction goals depend on correct accounting of all sources

Main Results

- Western US forests are net carbon sinks despite losses due to harvesting, wood product use, and combustion by wildfire
- 81% of the wood removed from west coast forests since 1900, has been returned to the atmosphere or deposited in landfills

Conclusions

- GHG budgets may be underestimated by up to 50% in some states
- Because GHG emissions from forestry operations are underestimated, claimed reductions will be insufficient to mitigate climate change

Methods Outline (Optional)

We calculated cradle-to-grave emissions for all carbon (C) captured in forest biomass and released through decomposition ecosystems and the wood products industry in Washington, Oregon, and California. We accounted for all C removed from forests through fire and harvest. C was tracked until it either was returned to the atmosphere through wood product decomposition/combustion or decomposition in landfills. This required calculating the C removed by harvest operations starting in 1900 to present day because some of that wood is still in-use or decomposing. In addition to C in biomass, we accounted for all C emissions associated with harvest (equipment fuel, transportation, manufacturing inputs). Moreover, our wood product life-cycle assessment includes pathways for recycling and deposition in landfills.

Acknowledgements