WILDFIRE RESILIENCE INSURANCE:

Quantifying the Risk Reduction of Ecological Forestry with Insurance

The Nature Conservancy

Willis Towers Watson

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This project and paper were funded in part through an Innovative Finance in National Forests Grant (IFNF) from the United States Endowment for Forestry and Communities, with funding from the United States Forest Service (USFS). The United States Endowment for Forestry and Communities, Inc. (the "Endowment") is a not-for-profit corporation that works collaboratively with partners in the public and private sectors to advance systemic, transformative and sustainable change for the health and vitality of the nation's working forests and forest-reliant communities.

We want to thank and acknowledge Placer County and the Placer County Water Agency (PCWA) for their leadership and partnership with The Nature Conservancy and the US Forest Service on the French Meadows ecological forest project and their assistance with the Wildfire Resilience Insurance Project and this paper. We would like in particular to acknowledge the assistance of Peter Cheney, Risk and Safety Manager, PCWA and Marie L.E. Davis, PG, Consultant to PCWA.

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Executive Summary

California is burning. Compounding impacts of climate change, the large number of homes and businesses built within or adjacent to forests or other lands at risk of wildfire, and insufficient resources dedicated to proactive ecologically based forest management are demonstrated by the growing acreage burnt each year. This problem is exacerbated by progressively longer fire seasons, affecting more and more people and having higher and higher direct and indirect economic costs. With more than 2.7 million Californians living in very high wildfire hazard severity zones, and the spike over the last few years in the number and severity of wildfires in California causing billions of dollars in damage, practices to reduce wildfire hazard are paramount.

Forests cover about 33 million acres in California - about one-third of California's land area - containing over 4 billion live trees. The largest share of forest lands is federally owned. Close to 60 percent (nearly 19 million acres) of forestlands in California are owned by the federal government, including the U.S. Forest Service (USFS), Bureau of Land Management (BLM), and National Park Service. About one-quarter (8 million acres) of forestland is in private non-industrial ownership. These owners include families, individuals, conservation and natural resource organizations, and Native American tribes. Industrial owners - primarily timber companies - own 14 percent (4.5 million acres) of forestland. State and local governments own a comparatively small share - only 3 percent (1 million acres) combined.[1] More resources -both public and private- are needed to actively manage forestlands to improve forest health and reduce wildfire risk. The USFS, in collaboration with the US Endowment for Forests and Communities and the National Forest Foundation, established the Innovative Finance for National Forests (IFNF) grant program to fund the development and implementation of innovative finance models that leverage private capital to support the resilience of the National Forest System and surrounding lands.[2] The Nature Conservancy was awarded an IFNF grant to assist in undertaking the Wildfire Resilience Insurance study which is the subject of this report.

In 2018 California wildfires took 103 lives, destroyed 24,000 structures, and cost $26 Billion in property damage and fire suppression costs. © Ben Jiang /TNC Photo Contest 2019

1 California Legislative Analyst's Office. 2018. Improving California's Forest and Watershed Management. https://lao.ca.gov/Publications/Report/3798

The objective of the Wildfire Resilience Insurance project and study is to determine whether the wildfire risk reduction associated with "ecological forestry", applied at landscape scale can be accounted for in insurance modeling and structuring and to quantify the insurance benefits of ecological forestry including any reduction in expected losses and consequential technical and actual premium savings. The project also explored how insurance premium savings might be used to fund or finance additional investments in ecological forestry in national and other forest lands. Ecological forestry involves using prescribed fire and strategic thinning to manage forests so they are healthier, more resilient to drought, fire and a warming climate. and there is a reduced risk of high-severity wildfire, as described in TNC's report, "Wildfires and Forest Resilience: The Case for Ecological Forestry in the Sierra Nevada".[3]

Viewed through a risk management lens, wildfire risk in California and throughout the western United States is becoming uninsurable. Risk is the product of **hazard** (the combination of the probability of wildfire and its characteristic intensity), **exposure** (where the item at risk is located and its value), and **vulnerability** (how damaging wildfire is to the item at risk).

In the case of insurance availability and pricing, for a given exposure (e.g., an office building in a location within the Wildland-Urban Interface, WUI), the hazard is growing quickly, while the ability to increase the wildfire resilience of the building (i.e., reduce the level of damage endured for a given intensity of wildfire impact) is limited. If either the hazard becomes high enough, or vulnerability cannot be reduced sufficiently, insurance will be either increasingly unaffordable, or unobtainable.

With an upper ceiling on how much an individual asset or, indeed, an entire community can reduce its vulnerability to wildfire, and acknowledging that exposure in the WUI continues to grow, reducing the wildfire **hazard** is critically important to reducing overall wildfire risk. More ecological forestry at landscape scale – pro-actively managing natural vegetation including forests, as was natural up until the last century or so, using naturally ignited and intentional fire to improve forest health and reduce undergrowth and ladder fuels which in turn reduces the likelihood of severe wildfires – is essential to reduce wildfire hazard. The advent of ecologically based thinning in the latter half of last century also furthers this goal and is now an accepted ecological forestry practice. Proactive forest management through ecological forestry also provides other benefits, including reduction in erosion (where high-severity fire is avoided) and improved water supply and water quality and broader ecosystem benefits such as the maintenance and restoration of biodiversity. Improving forest health and reducing the incidence of severe wildfires also increases the forest's ability over time to sequester carbon, which in turn can contribute to reducing the rate of carbon dioxide accumulation in the atmosphere, thereby helping to mitigate the very climate change that is fueling high-severity wildfires.

In this study, we assess whether and to what extent the severe wildfire risk reduction benefit of ecological forestry can be accounted for in insurance modeling and structuring. We use the French Meadows Project, a landscape scale ecological forestry project in national forest lands (Tahoe National Forest) in Placer County, California in the northern Sierra Nevada, and apply an insurance lens to capture one aspect of the economic value of the severe wildfire risk reduction benefit of ecological forestry through parametric and indemnity insurance modelling. We also consider the contribution that insurance premium savings from ecological forestry practices might make to ecological forestry projects in national forests and other forest lands.

The Placer County Water Agency is a partner with The Nature Conservancy and the US Forest Service in the French Meadows Project. We use the Placer County Water Agency (PCWA), and its assets in and around the French Meadows Project area, as the basis for analyzing core insurance use-cases incorporating the risk reduction benefits of ecological forestry, and we expand the analysis to broader, more theoretical cases such as the entire watershed,[4] to fully explore the insurance aspects of the wildfire hazard reduction benefits of ecological forestry.

2 Innovative Finance in National Forests (IFNF) Grant Program. https://www.nationalforests.org/grant-programs/innovative-finance-for-national-forests-grant-program

3 Kelsey, R. 2019. Wildfires and Forest Resilience: the case for ecological forestry in the Sierra Nevada. Sacramento, California, The Nature Conservancy. https://www.scienceforconservation.org/products/wildfires-and-forest-resilience

4 We refer here and throughout this paper to "watershed" as being the North Fork American River sub-basin (HUC8-18020128) as technically defined by the US Geological Survey (https://www.usgs.gov/core-science-systems/ngp/national-hydrography/watershed-boundary-dataset) except where explicitly stated otherwise.

PCWA has indemnity insurance covering its hydro power and water supply facilities and assets. Under this arrangement, each asset is assigned a value and in the event of damage to that asset a pay-out to the policy holder is made after the evaluation of the damage is made and the pay-out is based on the damage to the insured asset.

With regard to residential indemnity insurance premium savings associated with ecological forestry, a representative residential portfolio composed of more than 80,000 properties distributed in the watershed and surrounding area and totaling an annual premium of over $51 million was analyzed, in addition to analyzing whether taking account of ecological forestry would lower premium costs for indemnity insurance for PCWA assets.

We found substantial savings in aggregate annual home insurance premiums of 41% or ~$21.1 million, assuming, for purposes of analysis, the application of ecological forestry at landscape scale such that it positively impacts, from a wildfire risk perspective, on the full North Fork American River sub-basin. Premium savings results of 52% for home insurance accounting for ecological forestry also were obtained when analyzing a single community of 533 homes in the watershed.

While the study found that because most PCWA water and power facilities are of such construction that they are not vulnerable to significant wildfire damage (e.g., dams, reservoirs, tunnels, etc.) so there was not a demonstrable benefit to indemnity insurance pricing for those assets from ecological forestry, there was a significant reduction in indemnity insurance premium associated with taking into account ecological forestry for a subset of PCWA buildings which are vulnerable to damage by wildfire. When analyzed separately, the indemnity insurance premium cost for PCWA buildings vulnerable to wildfire in the watershed see a reduction in insurance annual indemnity premiums between 10% and up to 84%, with a 44% reduction on average (13 buildings analyzed).

There are, however, considerable non-insured costs related to a wildfire event for a water and power agency like PCWA that can be significant and can manifest either right after an event, such as the cost of removing burned debris/logs which end up in the waters of the PCWA watershed and then are carried into PCWA reservoirs, hydro power bays, or other PCWA hydro-power facilities and then interfere with PCWA hydro-power generation operations, or such as post-fire debris or sediment flows from erosion triggered by rainfall which also interferes with hydro-power generation operations, and which can be highly destructive and one of the most dangerous post-fire hazards.[5] The potential of damage by debris flow is greatest in the months to several years after a fire event has occurred and in fact, PCWA spent about $1 million in the year following the King Fire in 2014 to remove debris from one of its hydro-power plant after bays,[6] and it spent at least an additional $6 million to remove sediment from PCWA facilities following a heavy rainfall in early 2017.[7] In addition, the USFS undertook an analysis in the immediate aftermath of the 2014 King Fire which determined that undertaking aerial mulching of 1,730 acres of forest service lands would reduce sediment flows from the treated area by 77%, in turn reducing sediment by 34,365 tons. The USFS offered to undertake the aerial mulching of that acreage for $1.3 million.[8] While PCWA declined to incur that expense, post-fire sediment erosion mitigation costs is another category of potential cost associated with wildfire not covered by indemnity insurance.

Sediment and debris build up near PCWA Ralston AfterBay Dam. © Placer County Water Agency

5 https://ca.water.usgs.gov/wildfires/wildfires-debris-flow.html

6 PCWA Memorandum Re: Ralston After Bay Debris Management Project, Contract No 2015-15, Contract Change Order No. One, 6/23/2016. Listing project expenses to date as $930,969.56 to remove debris from PCWA Ralston After Bay.

7 PCWA Memorandum Re: 2017 Middle Fork American River Project Sediment Removal Project- Budget Amendment,4/6/2017. Approving a budget amendment to allocate $5 million to sediment dredging/removal. "This winter sediment accumulation has been far greater than normal and now impedes the reservoirs reducing the capability of the Middle Fork Project to divert water, manage its flow, and produce power. With approval of project funding, design and permitting will proceed immediately. Construction is scheduled for fall 2017. The estimated cost is $5,000,000."

See also PCWA Memorandum Re: Santos Excavating Inc. 2018 Sediment Dredging Services Agreement, 12/18/2017, increasing sediment removal project budget from $5 million to $6 million. "In early 2017, the Middle Fork Project experienced record historic storms that eroded large areas of recently burned terrain within the watershed resulting in the deposition of large volumes of sediment in project rivers and reservoirs. The winter sediment accumulation has been far greater than normal and now impedes the ability to operate the Low-level Outlet at Ralston Afterbay Dam. Currently we are out of compliance with dam safety requirements set forth by the California Department of Water Resources, Division of Safety of Dams. The Low-level Outlet slide gate is fully buried and is currently inoperable. Up to 5,000 cubic yards of material is estimated for removal in order to re-establish normal operability." ..."In 2017, use of $5,000,000 from the MFPA Capital Reserve Account was approved by a Budget Amendment...for sediment removal efforts. An additional $1,000,000 has been approved for 2018."

The study also analyzed the risk reduction and premium savings associated with ecological forestry for a range of parametric wildfire insurance structures which could provide funds to pay for the additional costs to PCWA associated with a severe wildfire discussed above. Parametric insurance, unlike more traditional indemnity insurance, pays out when a previously defined "parameter" is met or exceeded. For example, parametric insurance for wildfire risk could pay out when a certain threshold of "acres burned" is exceeded, as opposed to the insured having to prove that it suffered damage and loss to insured assets from a wildfire as is the case with a traditional indemnity insurance product.

With a parametric insurance product, a pay-out is made in the event of a fire which exceeds certain characteristics and as such, it can provide instant access to funds to pay for costs not covered by indemnity insurance, such as heavy debris removal, sediment removal, and/or erosion and sediment mitigation expenses discussed above.

With this study, for the first time an innovative wildfire parametric insurance product has been developed based on acreage burned and severity of burned acreage. The wildfire parametric insurance was designed for three different use cases, reflecting three different categories of costs associated with a wildfire. Two of the use cases are relevant specifically to the PCWA, based on PCWA's experience and costs in the wake of the 2014 King Fire and heavy debris and sediment impacts on PCWA's power generation assets and operations, while the third is a more conventional use-case for parametric wildfire insurance, designed to compensate a forest owner for the loss of commercial timber and the carbon storage value of the trees.

In order to quantify the insurance benefits of ecological forestry, the wildfire parametric insurance products were modeled and structured with and without accounting for the risk reduction benefit of ecological forestry, which was itself tested at different scales. Furthermore, the wildfire parametric insurance products developed for the first time for this study are tested at different scales (in terms of area of forest insured).

The main results of the parametric insurance analysis are promising across all modeled scales of insured area. Parametric insurance premium estimates (based on expected loss) decrease with ecological forestry, with 10% to 80% reductions across all modeled scenarios, and 20% to 40% reductions for case study scenarios consistent with the scale of the French Meadows ecological forestry project. The premiums decrease because ecological forestry management reduces both the total burned area and high severity burned area of wildfires,[9] in turn through reducing both frequency and severity of wildfire at any given location. For a given area of forest treated with ecological forestry, parametric premiums reduced by different amounts because of different sizes of insured areas, different insurance structures (reflecting different potential use cases and purchasers), and whether the designed structure takes advantage of the change in loss profile induced by the ecological forestry. Overall, the reduction of parametric premiums aligned with results of the indemnity modeling, though we note that real-world circumstances make the parametric insurance savings more easily materialized.

The table on the next pages displays the insurance premium savings results for the parametric wildfire resilience insurance scenarios and use cases, when ecological forestry is accounted for.

8 See analysis of aerial mulching costs and benefits provided by USFS Burned Area Emergency Management team to PCWA staff after the 2014 King Fire. Provided by PCWA staff to the authors.

9 We note that the impact of ecological forestry on individual wildfires varies, particularly with prevailing meteorological conditions. While the wildfire modeling on which we rely covers a range of conditions around the average, it does not cover wildfires burning under extreme meteorological conditions, particularly very strong winds, where the positive impacts of ecological forestry are likely to be significantly diminished.

Insurance Premium Savings Results

Client	Defined Area	Area insured (acres)	Use-case	Tick (average pay-out per acre burned, $)	Event Attach (acres)	Event Exhaust (acres)	Event deductible ($)		Event Limit ($)	Scenario	Area with ecological forestry (acres)	Area benefitting from ecological forestry fire suppression (acres)	Insurance Type	Annual Premium ($)	Insurance savings (%)
PCWA	A tightly defined region around French Meadows and Hell Hole reservoirs	20,000	(i) Debris removal	300	100	8,433	30,000		2,500,000	(i)(a)	None	None	Burned Area, no ecological forestry	144,000	-
													Burned Severity, no ecological forestry	135,000	6%
										(i)(b)	12,183	40,610	Burned Area with ecological forestry	115,000	20%
													Burned Severity with ecological forestry	105,000	27%
			(ii) Slope stability treatment	1,000	100	5,100	100,000		5,000,000	(ii)(a)	None	None	Burned Area, no ecological forestry	330,000	-
													Burned Severity, no ecological forestry	295,000	11%
										(ii)(b)	12,183	40,610	Burned Area with ecological forestry	290,000	12%
													Burned Severity with ecological forestry	240,000	27%
	The hydrological watershed above the French Meadows reservoir that benefits from all ecological forestry across the project area	40,610	(i) Debris removal	148	100	17,021	14,775		2,500,000	(i)(c)	None	None	Burned Area, no ecological forestry	155,000	-
													Burned Severity, no ecological forestry	147,000	5%
										(i)(d)	12,183	40,610	Burned Area with ecological forestry	130,000	16%
													Burned Severity with ecological forestry	120,000	23%
			(ii) Slope stability treatment	492	100	10,253	49,249		5,000,000	(ii)(c)	None	None	Burned Area, no ecological forestry	365,000	-
													Burned Severity, no ecological forestry	334,000	8%
										(ii)(d)	12,183	40,610	Burned Area with ecological forestry	340,000	7%
													Burned Severity with ecological forestry	293,000	20%
Hypothetical timber stakeholder	A large region of importance to a hypothetical timber stakeholder	90,000	(iii) Lost timber assets	1,000	5,000	17,500	5,000,000		12,500,000	(iii)(a)	None	None	Burned Area, no ecological forestry	1,000,000	-
													Burned Severity, no ecological forestry	975,000	3%
										(iii)(b)	28,000	93,333	Burned Area with ecological forestry	780,000	22%
													Burned Severity with ecological forestry	640,000	36%

Next, we compared the insurance premium savings associated with several of the use cases, to the underlying cost of the ecologically treated forest acreage associated with that use case. For purposes of this analysis, ecological forestry was defined as consisting of prescribed burning and thinning of forest acreage. The cost of ecological forestry varies significantly depending on the topography and location of the acreage where it is being applied. We assume a cost of $1,000 per acre for both thinning and prescribed burning, consistent with the latest cost estimates from the US Forest Service.[10] We then calculated the cost of ecological forestry for each use case and compared the associated insurance premium savings to the cost of ecological forestry.

The table below provides the results of the comparison of insurance premium savings to ecological forestry costs for the parametric wildfire resilience insurance use cases and scenarios.

Comparison of Insurance Premium Savings to Ecological Forestry Costs for the Parametric Insurance Use Cases and its Scenarios

Scenario	Use Case	Ecological forestry	Area insured (acres)	Annual Premium ($)	Insurance savings compared to Burned Area with no ecological forestry ($)	Insurance savings compared to Burned Area with no ecological forestry (%)	Ecological - forestry costs offset per year from insurance savings (%)
1a	Debris removal	No	20,000	135,000	9,000	6.3%	-
1b	Debris removal	Yes	20,000	105,000	39,000	27.1%	0.3%
2c	Slope stability/ debris removal	No	40,610	334,000	31,000	8.5%	
2d	Slope stability/ debris removal	Yes	40,610	293,000	72,000	19.7%	0.6%
3a	Lost timber assets	No	90,000	975,000	25,000	2.5%	
3b	Lost timber assets	Yes	90,000	640,000	360,000	36.0%	1.3%

10 See Clavet, C., Topik, C., Harrell, M., Holmes, P., Healy, R., and Wear, D. May 2021. Wildfire Resilience Funding: Building Blocks for a Paradigm Shift. The Nature Conservancy, Arlington, Virginia, p. 8. "Treatment costs per acre can vary widely based on a large number of factors such as location, treatment type, planning and implementation costs. A very broad average is derived from the Forest Service Forest Activity Tracking System (FACTS) of $1,000 per acre."

For each of the parametric wildfire resilience insurance use cases, one year's worth of insurance savings is a small share of the associated cost of ecological forestry. However, as further elaborated below, premium savings are annual whereas ecological-forestry costs are incurred at the onset and then over intervals of 15 years or so. Further, the greatest asset values are at risk in the WUI and are captured in residential and commercial property, so it is to be expected that the benefits of ecological forestry will be maximized here.

As the table below shows, aggregate residential premium savings from ecological forestry indeed compare favorably to ecological forestry costs over time. The net savings increase with the duration of the program, ranging from approximately $15.57 million for 10 years to $120.57 million over 15 years. The annualized treatment costs are less than the annual premium savings for all time periods, leading to an increasing benefit-cost ratio (1.08 vs. 1.62) as the effective duration of the treatment is extended. In other words, the benefits accrued increase the longer the ecological forestry program is in place.

One way in which the insurance savings might be used to fund or finance ecological forest treatment in national or other forests lands would be through the issuance of bonds, with the insurance savings applied to pay the debt service over time on the bonds. The proceeds from the bond issuance would be used to fund ecological forestry.

Assuming that the insurance savings for the use cases and scenarios persist over a ten to fifteen-year period, we calculated the amount of bond financing that the insurance savings could support if paid as debt service on the bonds. We then calculated the amount of acreage which could be treated in each case, with the bond proceeds. The table below indicates the varying levels of forest treatment acreage that could be funded assuming the insurance savings persist 10 and 15 years respectively and that they are used to pay debt service on bonds issued to fund ecological forest treatment.

Comparison of Aggregate Residential Premium Savings to Ecological Forestry Costs

Duration (years)	Ecological forest treatment costs ($M)	Total Premium Savings ($M)	Net Savings ($M)	Benefit-Cost Ratio
10	194.43	210	15.57	1.08
15	194.43	315	120.57	1.62

Bond Financing for Forest Treatment

10-year						
Scenario	Issuer	Interest rate	Bond amount ($M)	Treatment costs ($M)	Acres treated	% Treatment cost offset by insurance savings
1b	PCWA	1.25%	0.37	12.2	366	3%
2d	PCWA	1.25%	0.68	12.2	676	6%
3b	Timber owner	2.2%	3.38	28.0	3,382	13%
4	Municipality	1.25%	197.31	194.4	197,309	108%
15-year						
Scenario	Issuer	Interest rate	Bond amount ($M)	Treatment costs ($M)	Acres treated	% Treatment cost offset by insurance savings
1b	PCWA	1.5%	0.52	12.2	524	5%
2d	PCWA	1.5%	0.97	12.2	967	9%
3b	Timber owner	2.8%	4.83	28.0	4,833	19%
4	Municipality	1.5%	281.92	194.4	281,920	162%

We note that benefits should increase over longer time periods, as successive ecological forestry interventions are likely to be cheaper on a per-acre basis.

In addition to the important results described above, this project also demonstrates that ecological forestry can be accounted for in insurance modeling and pricing. Insurers and catastrophe modeling firms who license wildfire risk score models for insurers, should incorporate the findings of this study in their wildfire risk score models, so that homes whose wildfire risk is reduced due to ecological forest treatment see the benefit of that risk reduction in the risk score assigned to the home by the wildfire risk score model used to determine whether or not to renew or write insurance for the home.

Both private home insurers and the California FAIR Plan[11] should incorporate the findings of this study in their rate development and modeling, so that where ecological forestry is occurring at landscape scale, rates for both the FAIR Plan and private home insurance will take into account the risk and expected loss reduction benefits of ecological forestry. This will immediately drive the scale and scope of de-risking activities that are required to maintain the availability of wildfire insurance across California.

A next step would be to pilot a wildfire resilience insurance product with commercial or public property or asset owners or a community, where ecological forestry has or will occur at sufficient scale such that the risk of severe wildfire is reduced.

Water and power agencies located in national or other forest lands in the western United States, where ecological forest treatment is occurring so as to reduce wildfire risk in some or all of their watershed, present one such opportunity to pilot wildfire resilience insurance. Private timber companies whose lands are or will be ecologically managed or whose assets are in or adjacent to national or other forests where ecological forestry is occurring at sufficient scale present another potential for a pilot project. Ski resorts with commercial and/or residential structures vulnerable to wildfire may also present an opportunity to pilot wildfire resilience insurance while contributing insurance premium savings to fund or finance ecological forest treatment in adjacent national or other forests.

Another opportunity to pilot wildfire resilience insurance might be asset or property owners who are issuing a forest conservation bond like that piloted by Blue Forest Conservation. Wildfire Resilience Insurance might be piloted as an adjunct to complement a forest conservation bond.

Residential communities adjacent to national or other forest lands undergoing ecological forest treatment also present an opportunity to pilot a community based wildfire resilience insurance product or to otherwise capture residential insurance premium savings through a property fee or assessment on homeowners whose insurance price will be lower due to ecological forest management.

This is not an exhaustive list, but is indicative of the potential opportunities to pilot wildfire resilience insurance to demonstrate how insurance savings associated with ecological forestry in national or other forest lands might be used to fund or finance ecological forestry.

11 https://www.cfpnet.com/. “The California FAIR Plan Association was established in 1968 to meet the needs of California homeowners unable to find insurance in the traditional marketplace.”

Communities within or adjacent to forest lands face risk of severe wildfire in California. © PixieMe/Shutterstock

Section 1: Introduction

More than 2.7 million Californians live in very high wildfire hazard severity zones. From trailers off quiet dirt roads in the forest to mansions in large cities adjacent to or containing forest lands and other lands at high risk of wildfire. (2010 block-level census data).[12] Figure 1-1 shows wildfire hazard distribution in the United States from Willis Towers Watson’s risk assessment proprietary tool: risk increases significantly from east to west, with hotspots in cities across the west-southwestern States, high risk in the State of Washington and California, and the highest risks focused in Northern and Southern California.

Forests cover about 33 million acres in California - about one third of California’s land area — containing over 4 billion live trees. The largest share of forest lands is federally owned. Close to 60 percent (nearly 19 million acres) of forestlands in California are owned by the federal government, including the U.S. Forest Service (USFS), Bureau of Land Management (BLM), and National Park Service. About one quarter (8 million acres) of forestland is in private non-industrial ownership. These owners include families, individuals, conservation and natural resource organizations, and Native American tribes. Industrial owners - primarily timber companies - own 14 percent (4.5 million acres) of forestland. State and local governments own a comparatively small share - only 3 percent (1 million acres) combined.[13] More resources — both public and private — are needed to actively manage forestlands to improve forest health and reduce wildfire risk.

The USFS, in collaboration with the US Endowment for Forests and Communities and the National Forest Foundation, established the Innovative Finance for National Forests (IFNF) grant program to fund the development

12 Sabalow, R., Reese, P., and Kasler, D. 2019. "Destined to Burn: California races to predict which town could be next to burn". The Sacramento Bee, April 11, 2019.
13 California Legislative Analyst’s Office. 2018. Improving California’s Forest and Watershed Management. https://lao.ca.gov/Publications/Report/3798

and implementation of innovative finance models that leverage private capital to support the resilience of the National Forest System and surrounding lands.[14] The Nature Conservancy was awarded an IFNF grant to assist in undertaking the Wildfire Resilience Insurance study which is the subject of this report.

The objective of the Wildfire Resilience Insurance project and study is to determine whether the wildfire risk reduction associated with "ecological forestry" can be accounted for in insurance modeling and structuring and to quantify the insurance benefits of ecological forestry including any reduction in expected losses and consequential technical and actual premium savings. This paper sets forth the results of the project and study. This paper also explored how insurance premium savings might be used to fund or finance additional investments in ecological forestry in national and other forest lands. Ecological forestry involves using prescribed fire and thinning to manage forests the way nature and indigenous people historically managed forests.

1.1 Increasing Risk of and Losses from Wildfires

Wildfires in California are influenced by a number of factors, including ignition sources, wind, and the amount of combustible brush. Environmental factors during the fire season play an especially crucial role. These include the drying of forest vegetation in the summer, particularly as the winter rains and spring snowmelt occur earlier each year as a result of climate change.[15]

The number of wildfires in California causing billions of dollars in damage has spiked over the last few years, as has the cost of wildfire across the American West (e.g., Burke et al., 2020[16]). While Southern California has seen an accumulation of such events since the early 2000s, the northern half of the state has only experienced a sharp rise in major loss events since 2013. Climate trends are clearly contributing to an increase in wildfire hazard, which is arguably higher now than it ever was in the 20th century. The overall risk and loss levels are significantly different

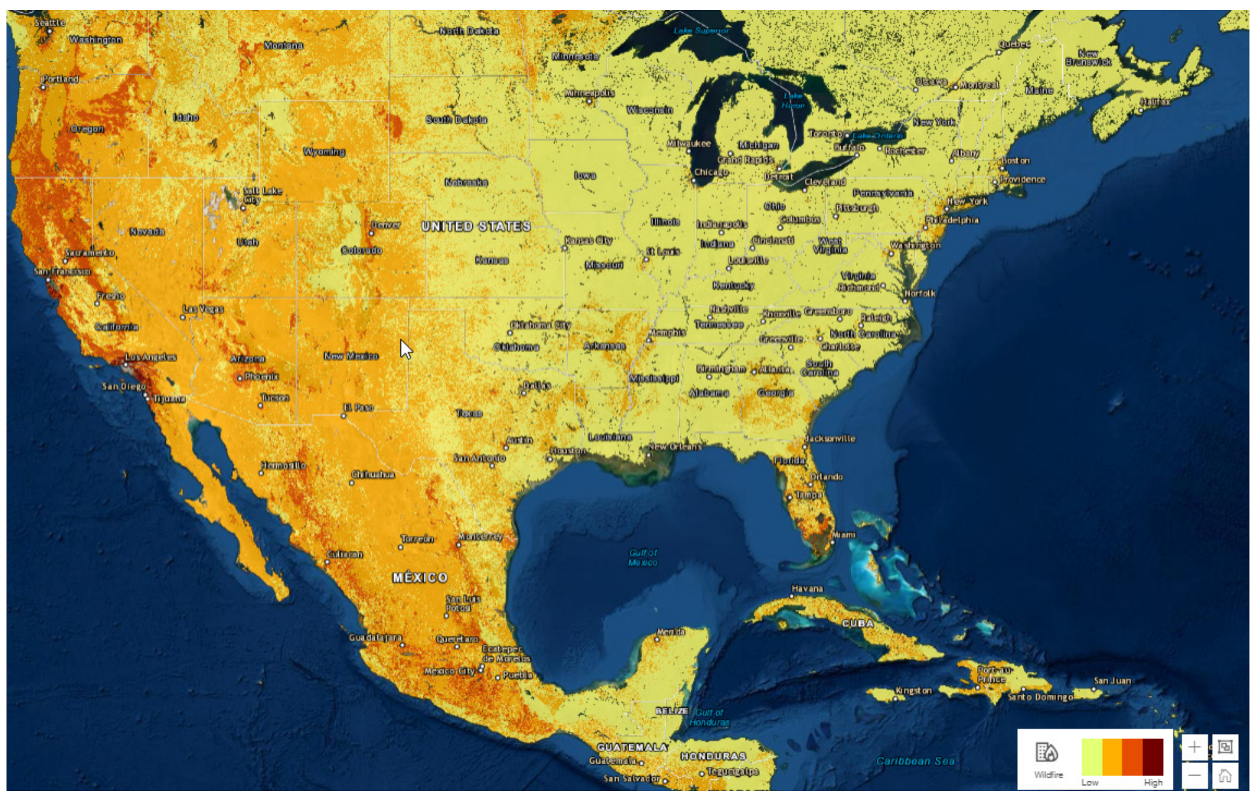


Figure 1-1. Wildfire Hazard (low to high) in the United States from Willis Towers Watson's proprietary risk assessment Global Peril Diagnostic tool.

14 Innovative Finance in National Forests (IFNF) Grant Program. https://www.nationalforests.org/grant-programs/innovative-finance-for-national-forests-grant-program

15 Westerling, A.L.R. 2016. Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. Phil. Trans. R. Soc. B 371: 20150178. http://dx.doi.org/10.1098/rstb.2015.0178

16 Burke, M, Heft-Neal, S, Wara, M. 2020. Managing the growing cost of wildfire. Palo Alto, California, Stanford University. SIEPR Policy Brief, October 2020.

than in the past. And as the state's climate continues to change, California will experience a further worsening of these conditions in the medium term[17] (Figure 1-2).

Wildfire-related insured global losses came to $15 billion in 2017 – a figure that was surpassed the following year ($18 billion). Especially severe fires caused billions of dollars in insured losses in Southern California in the years 2003, 2007, 2017 and 2018, while record losses in excess of $10 billion in 2017 and 2018 in Northern California are a strong indication that we have reached a new hazard level there as well. Previously, the only event in Northern California to exceed the billion-dollar insured loss threshold was the Tunnel Fire of 1991 with insured losses of $1.7 billion (original values, see Figure 1-3).

Dealing with crisis costs more than managing risk.

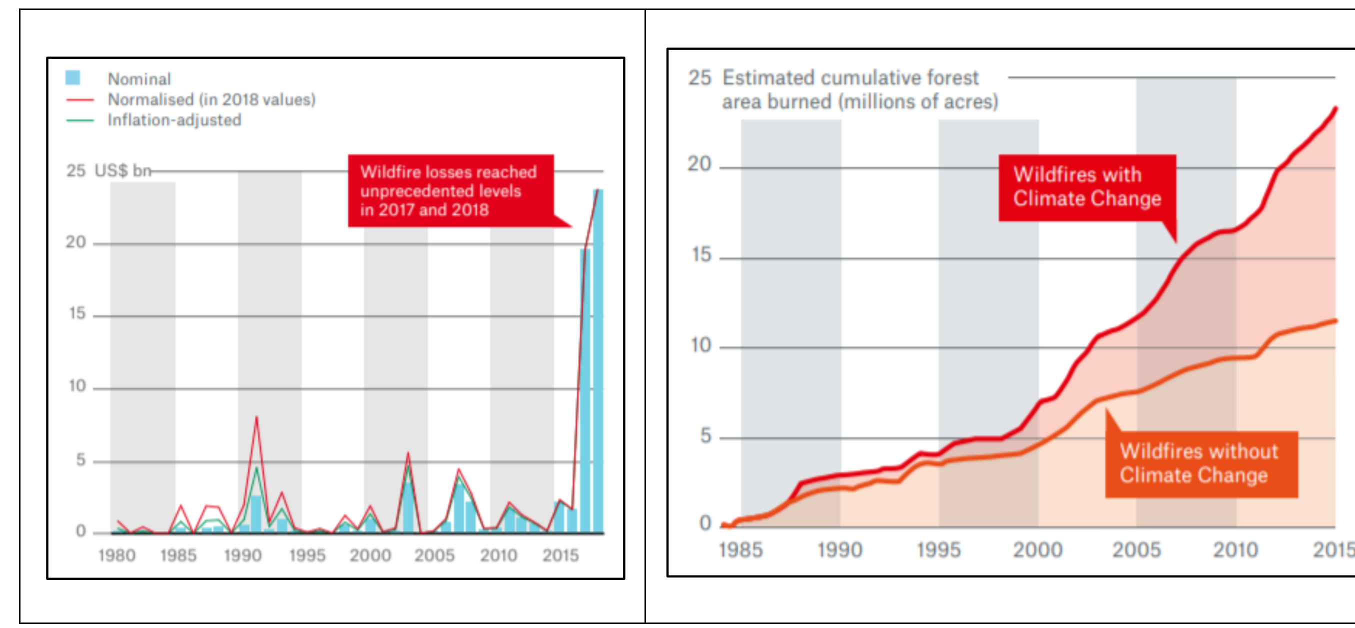


Figure 1-2. (left) Overall (economic) annual wildfire losses in California during the period 1980 to 2018 as reported by Munich Re. Blue bars show nominal losses, red line shows losses normalized to 2018 values, and green line shows the values only adjusted by inflation (to 2018). (right) Estimated cumulative forest area burned (in millions of acres) in the western U.S. over the period 1984 to 2015 with (red) and without (orange) climate change. Source: Munich Re (2019)[18]; for right panel, adapted from Abatzoglou & Williams (2016)[19].

17 Munich Re. 2019. New hazard and risk level for wildfires in California and worldwide. https://www.munichre.com/content/dam/munichre/global/content-pieces/documents/Whitepaper%20wildfires%20and%20climate%20change_2019_04_02.pdf

18 Munich Re. 2019. New hazard and risk level for wildfires in California and worldwide. https://www.munichre.com/content/dam/munichre/global/content-pieces/documents/Whitepaper%20wildfires%20and%20climate%20change_2019_04_02.pdf

19 Abatzoglou, J.T., and Williams, A.P. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences, Vol. 113 (42), pp. 11770-11775. https://doi.org/10.1073/pnas.1607171113

1.2 Insurance Losses from Wildfire in California

With over 1,300 insurance companies collecting over $310 billion in premiums annually and holding $5 trillion in assets under management, California is the US's largest insurance market and the fourth largest insurance market in the world. Public insurers assuming most crop and flood risks collect an additional $500 million each year in premiums in the California marketplace alone.[20]

From an insurance perspective, the Camp Fire in Northern California in November 2018 was the world's costliest single event of that year, resulting in insured losses of $12 billion. For comparison, next were Hurricane Michael in the US, and Typhoon Jebi in Japan[21] (see Figure 1-3). Such insured loss size is commonly seen from major perils such as Earthquake and Tropical Cyclones (i.e., hurricanes, typhoons, cyclones) and was unexpected from a wildfire event, which is traditionally considered a secondary peril. While the Camp Fire was the deadliest (at least 85 casualties) and most destructive (~18,800 structures) fire in the history of California[22], earlier in 2018 the Carr Fire caused an extremely rare "fire tornado" and the Mendocino Complex Fire, with about half a million burnt acres, became the largest in California history. And the year before, in 2017, wildfires caused $12.6 billion in insured loss, plus $658 million for the subsequent mudslides[23], approximately four times higher than in any previous year.

Due to the risk of wildfire in the Wildland Urban Interface (WUI) of California, home insurers are increasingly declining to renew or write new insurance and are significantly increasing the price of insurance for those homes that they continue to insure within the WUI. There are over four million Californian homes in the WUI, of which over a million face high to extreme risk of wildfire.[24]

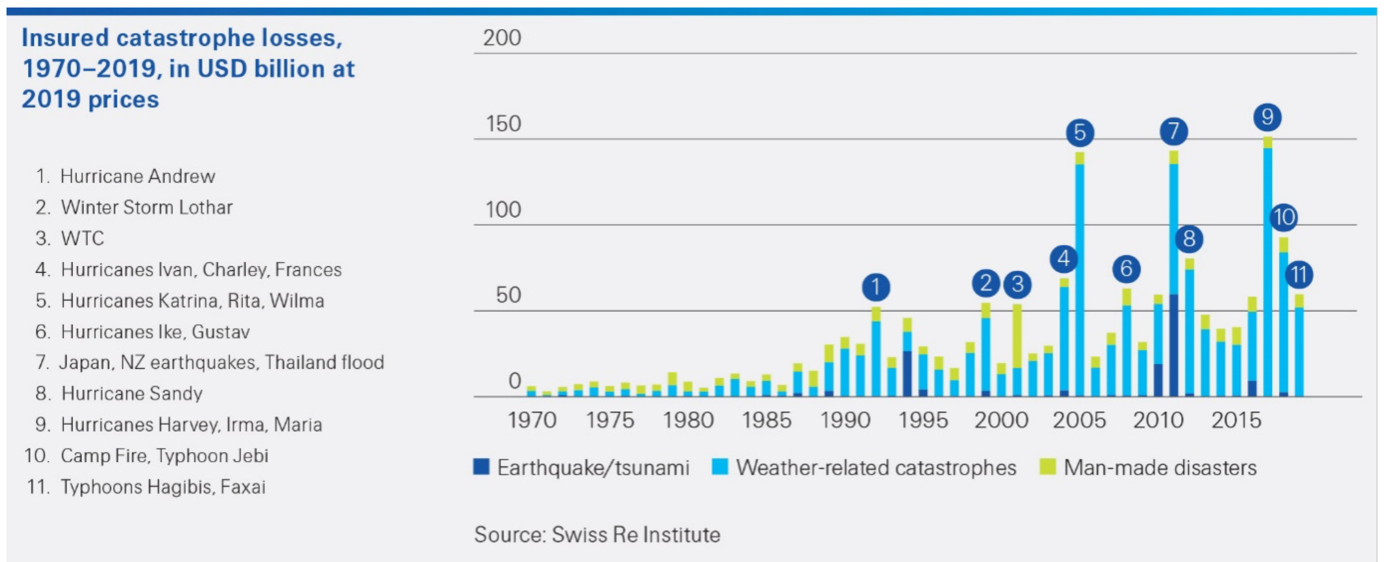


Figure 1-3. Global insured catastrophe losses for the period 1970 to 2019 (weather-related catastrophes in light blue), in USD billion at 2019 prices, as collected and reported by Swiss Re Institute.[25] Notable is the Camp Fire loss in 2018 (denoted by 10), a size of loss (USD 12 billion) typically only seen for major perils such as Hurricanes or Earthquakes.

20 As per former California Insurance Commissioner's Dave Jones's Press Release on April 5, 2018. http://www.insurance.ca.gov/0400-news/0100-press-releases/2018/release034-18.cfm
21 Swiss Re Institute. 2019. Swiss Re sigma No. 2/2019.
22 According to the California Department of Forestry and Fire Protection (CAL FIRE), e.g., https://www.fire.ca.gov/media/5121/campfire_cause.pdf
23 Mills, E., Lamm, T., Sukhia, S., Elkind, E., and Ezroj, A. 2018. Trial By Fire: Managing Climate Risks Facing Insurers in the Golden State. Sacramento, California, California Department of Insurance.
24 California Department of Insurance. 2017. The Availability and Affordability of Coverage for Wildfire Loss in Residential Property Insurance in the Wildland-Urban Interface and Other High-Risk Areas of California: CDI Summary and Proposed Solutions. Sacramento, California, California Department of Insurance.
25 Swiss Re Institute. 2020. Swiss Re sigma No. 2/2020.

Between 2018 and 2019, there was a 31% increase in non-renewals of home insurance by insurance companies operating in California. According to the California Department of Insurance, most of the growth in non-renewals is occurring in areas with higher wildfire risk. In zip codes covering areas with moderate to very high wildfire risk, there was a 61% increase in non-renewals. In the ten counties with the highest exposure of homes to high or very high fire risk, there was a 203% increase in non-renewals.[26]

Absent a formal definition, insurance industry practice has been to consider secondary perils as high-frequency, low-to-medium severity loss events. Secondary perils can happen on an independent basis, such as river floods, flash floods, hailstorms, tornadoes and straight-line winds, snow and ice storms, drought and wildfire outbreaks. The events often appear as secondary effects of primary perils, such as storm surge or torrential precipitation. Recently, high severity losses arising from secondary perils, such as California wildfires, Hurricane Harvey's torrential precipitation, and Hurricane Sandy's storm surge, have triggered catastrophe model reviews and/or catastrophe model revisions across the board, and the need to re-think the definition of such perils.

1.3 Climate Change

There is clear evidence to show that climate change is happening. Measurements indicate that the average temperature at the Earth's surface has risen by about 1°C since the pre-industrial period. Seventeen of the 18 warmest years on record have occurred in the 21st century[27] and each of the last three decades have been hotter than the previous one. This change in temperature hasn't been the same everywhere; the increase has been greater over land than over the oceans and has been particularly fast in the Arctic.[28] Along with warming at the Earth's surface, many other changes in the climate are occurring, such as warming oceans, melting polar ice and glaciers, rising sea levels and more extreme weather events of fundamental importance for the scope of this project.

According to the Intergovernmental Panel on Climate Change,[29] heat waves and droughts are expected to become more common and intense over the coming century, and more frequent heavy rainfall events and rising sea levels will increase the risk of floods. While not all extreme weather events can be directly linked to human influences, we are already seeing the huge impacts on society that extreme weather events can have. The World Meteorological Organization (WMO) reported[30] that between 2001 and 2010 extreme weather events caused:

- More than 370,000 deaths worldwide (including a large increase in heatwave deaths from 6,000 to 136,000) – 20% higher than the previous decade.
- An estimated US$660 billion of economic damage – 54% higher than in the previous decade.

While North America adaptive capacity is generally high, vulnerabilities still exist and one of them is the increased risk of wildfires in the western US.

Using data from IPCC AR5,[31] Figure 1-4 (top panel) shows projected changes in precipitation by the end of the century in all four seasons, with large decreases in the south and west and increases in the north. Figure 1-4 (bottom panels) also illustrates how summer temperatures are projected to change across America during the 21st century. It shows the projected change in summer temperature (a), precipitation (b), summer drought (c) and March snow (d) under various scenarios and timeframes. It is clear is that the summers will experience hotter, drier periods, with an increase in extreme precipitation events across California and a decrease in snow cover.

26 "Virtual Investigatory Hearing on Homeowners' Insurance Availability and Affordability", Presentation by the California Department of Insurance, October 19, 2020. , p. 18.
27 https://www.metoffice.gov.uk/news/releases/2018/2017-temperature-announcement
28 IPCC. 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York City, New York, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf
29 IPCC. 2014. Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York City, New York, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf
30 World Meteorological Organisation. 2013. The Global Climate 2001-2010: a decade of climate extremes – Summary Report. Geneva, Switzerland, World Meteorological Organisation.
31 https://www.ipcc.ch/assessment-report/ar5/

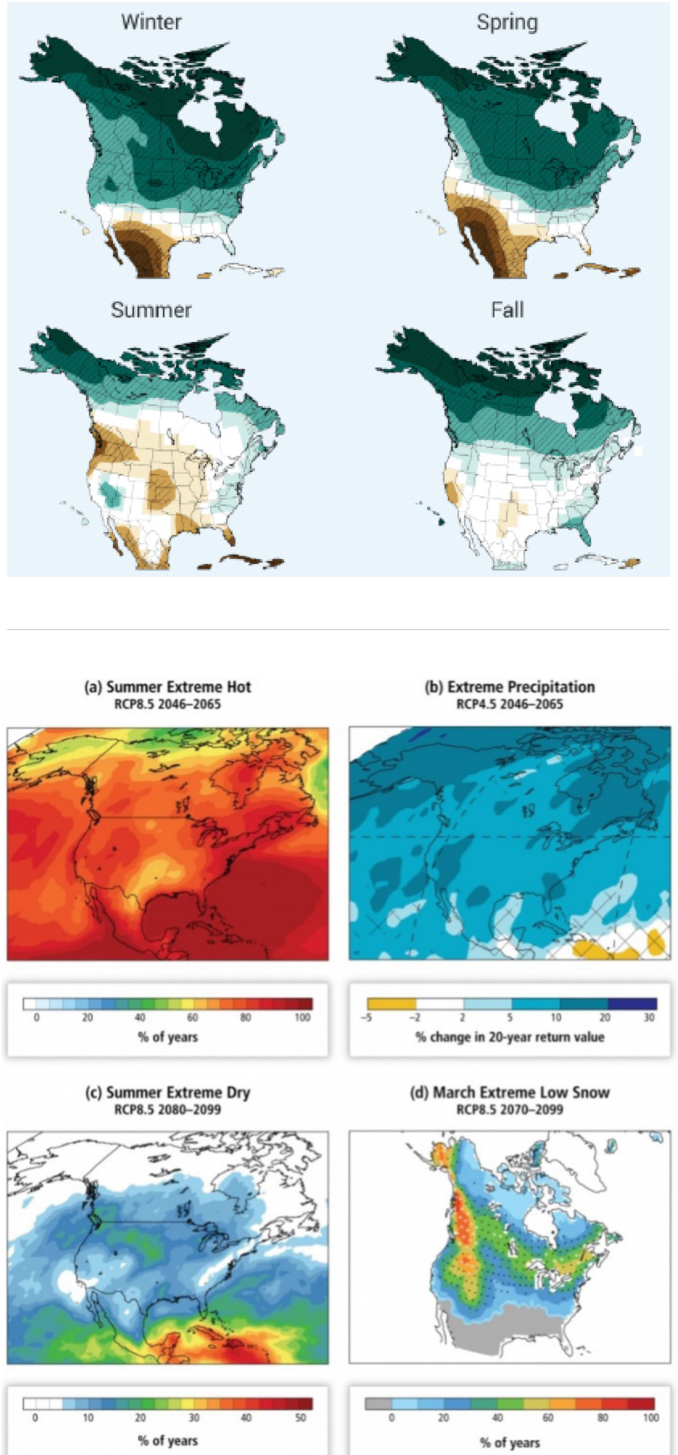


Figure 1-4. Top: IPCC AR5 precipitation change projections for 2100. Bottom: IPCC AR5 projected changes in extremes in North America.

1.4 Climate Change and Wildfire Risk in California

Many variables, including human behavior and land development patterns, affect the economic and insured losses associated with wildfires. However, a substantial and growing body of evidence suggests that increasing temperatures and shifting precipitation patterns associated with climate change is resulting in more frequent and more severe wildfires (e.g., US Fourth National Climate Assessment, 2018[32]; Goss et al., 2020[33]; McEvoy et al., 2020[34]; Swain, 2021[35]; Burke et al., 2021[36]; Higuera and Abatzoglou, 2021[37]).

Additionally, warm, dry winters and drought can create other damaging conditions in California's forests, including tree disease and outbreaks of insects such as the Western and Mountain Pine Beetles, all of which make forests more flammable and fires more intense (United States Department of Agriculture (USDA), 2006).[38]

Burned area has increased five-fold over the past four decades across California (Figure 1-5a) and in the Sierra Nevada (Figure 1-6b). Most notably, the increase in burned area occurs between May–September. This rise is due to both increased temperatures and increased vapor-pressure deficit (VPD, i.e., drier air) over the past four decades. Both air temperature and VPD between May–October are expected to continue increasing up to 2050 (Figure 1-6). The rise in temperatures and VPD indicate that wildfire burned area should be expected to continue to increase in the future.

32 https://nca2018.globalchange.gov/
33 Goss, M., Swain, D., Abatzoglou, J., Sarhadi, A., Kolden, C., Williams, A., and Diffenbaugh, N. (2020). Climate change is increasing the risk of extreme autumn wildfire conditions across California. Environmental Research Letters. 15. https://doi. org/10.1088/1748-9326/ab83a7.
34 McEvoy, D. J., Pierce, D. W., Kalansky, J. F., Cayan, D. R., & Abatzoglou, J. T. (2020). Projected changes in reference evapotranspiration in California and Nevada: Implications for drought and wildland fire danger. Earth's Future, 8, e2020EF001736. https://doi. org/10.1029/2020EF001736
35 Swain, D. L. (2021). A shorter, sharper rainy season amplifies California wildfire risk. Geophysical Research Letters, 48, e2021GL092843. https://doi.org/10.1029/2021GL092843
36 Burke, M., Driscoll, A., Heft-Neal, S., Xue, J., Burney, J., & Wara, M. (2021). The changing risk and burden of wildfire in the United States. Proceedings of the National Academy of Sciences, 118, e2011048118. https://doi.org/10.1073/pnas.2011048118
37 Higuera, P. E., & Abatzoglou, J. T. (2021). Record-setting climate enabled the extraordinary 2020 fire season in the western United States. Global Change Biology, 27, 1–2. https://doi.org/10.1111/gcb.15388
38 United States Department of Agriculture. 2006. Bark Beetles in California Conifers, are your Trees Vulnerable? Washington, DC, USDA.
39 Williams, A. P., Abatzoglou, J. T., Gershunov, A., Guzman- Morales, J., Bishop, D. A., Balch, J. K., and Lettenmaier, D. P. (2019). Observed impacts of anthropogenic climate change on wildfire in California. Earth's Future, 7, 892–910. https://doi.org/10.1029/2019EF001210

With climate change a contributing factor, the fire season in California is beginning earlier and ending later each year. According to Cal Fire, the fire season is estimated to have increased by 75 days across the Sierras, extending the threat of fast-spreading wildfires into the cooler months.[40] Warmer and drier-than-average spring and summer conditions, combined with below-average mountain snowpack, are resulting in dry fuel conditions, making forests more susceptible to severe wildfire.

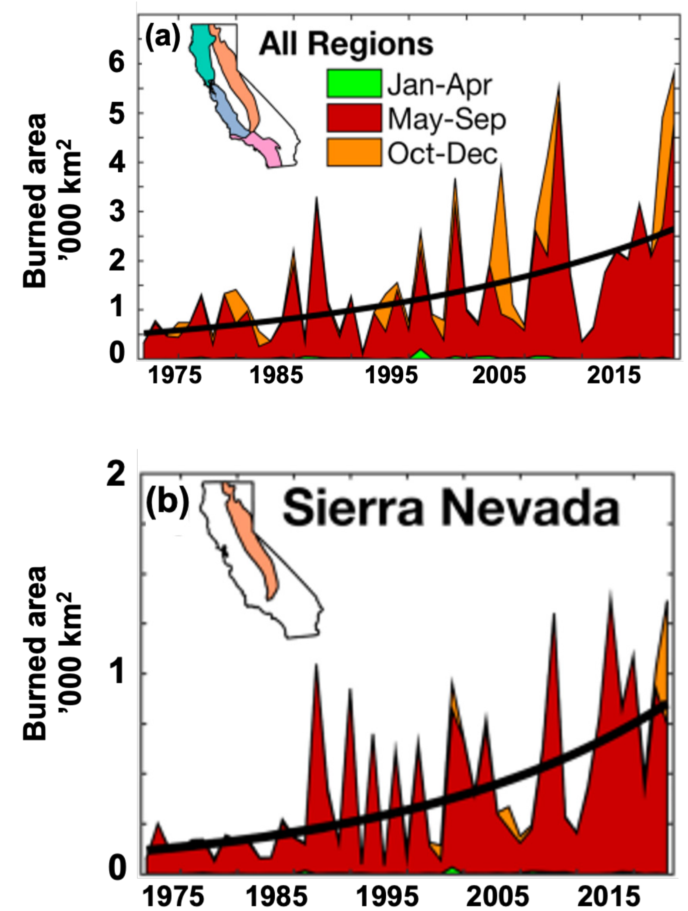


Figure 1-5. Seasonal and annual burned areas in California for 1972–2018. (a) Total burned area for the North Coast (green), Sierra Nevada (orange), Central Coast (light blue) and South Coast (pink) and (b) for Sierra Nevada only. Annual burned area is decomposed into that which occurred in January–April (green), May–September (red), and October–December (orange). Significant ($p < 0.05$) trends are shown as bold black curves. Figure and caption adapted from Williams et al. (2019).[41]

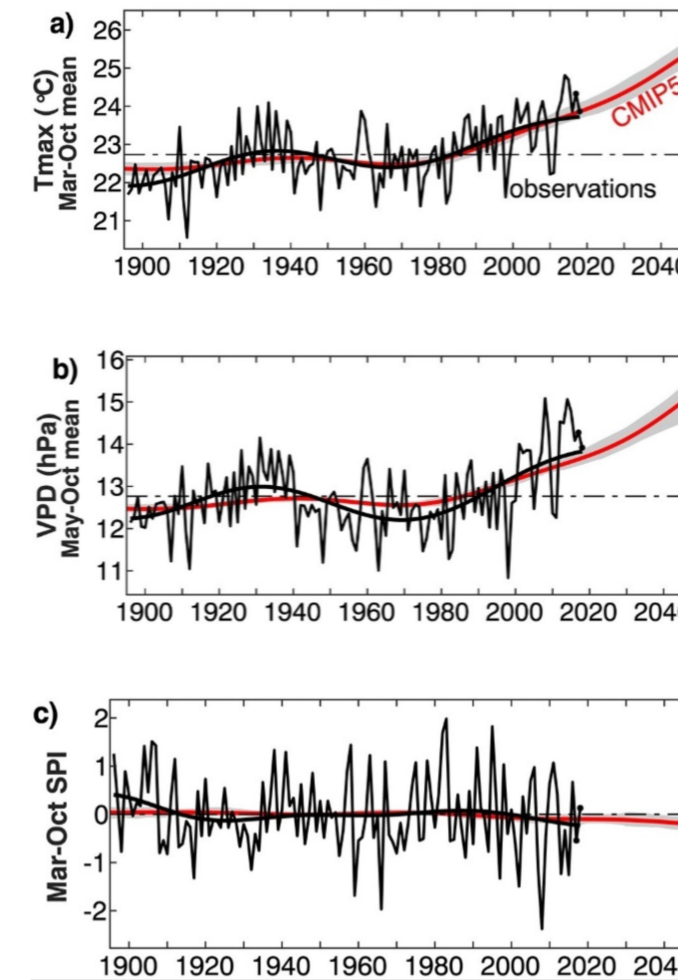


Figure 1-6. Mean all-region trends in climate variables important to summer wildfire. (a–c) March–October mean daily maximum temperature (Tmax), vapor-pressure deficit (VPD), and standardized precipitation index (SPI), respectively. Figure and caption from Williams et al. (2019).[42]

40 https://www.fire.ca.gov/incidents/2020/
41 Williams, A. P., Abatzoglou, J. T., Gershunov, A., Guzman- Morales, J., Bishop, D. A., Balch, J. K., and Lettenmaier, D. P. (2019). Observed impacts of anthropogenic climate change on wildfire in California. Earth's Future, 7, 892–910. https://doi.org/10.1029/2019EF001210
42 Williams, A. P., Abatzoglou, J. T., Gershunov, A., Guzman- Morales, J., Bishop, D. A., Balch, J. K., and Lettenmaier, D. P. (2019). Observed impacts of anthropogenic climate change on wildfire in California. Earth's Future, 7, 892–910. https://doi.org/10.1029/2019EF001210

1.5 Ecological Forestry: Improving Forest Health and Reducing Wildfire Risk

In addition to climate change, forests have also come under greater risk of severe fires due to human intervention. Logging practices have removed most of the older, fire-resistant trees and left large stands of forests where residual stands are densely packed with trees of similar ages and sizes. Over 100 years of fire suppression efforts to eliminate forest fires have resulted in forest stands that are unnaturally dense and dominated by seedlings, saplings, and middle-aged trees. These dense forests lack the structural diversity characteristic of older, native forests and are prone to severe fires and destruction.

Forests can become more wildfire resilient with ecological forestry practices. Ecological forestry management includes practices such as strategic thinning, controlled or prescribed burning, and managed wildfire. Strategic thinning involves the removal of trees and shrubs in targeted areas in an effort to reduce surface and ladder fuels while also increasing the health and diversity of the forest. Controlled or prescribed burning involves igniting small, controlled burns in targeted areas in an effort to reduce undergrowth and smaller trees while providing nutrients to the remaining vegetation. Managed wildfires are non-planned fires that are allowed to burn without being extinguished under certain circumstances and conditions (e.g., cultural burning, see Clark et al., 2021).[43]

Ecological forestry has been shown to reduce the severity of wildfires and is increasingly accepted in forest management practice that delivers multiple benefits. There are many advantages to ecological forestry; primary among them are healthier forests and reduction in risk of severe wildfires. "Through use of targeted ecological thinning, prescribed fire, and managed wildfire we can reduce the accumulated high fuel loads, promote healthier, more resilient forests, reduce the risk of high-severity wildfire at large spatial scales, and protect sensitive species", according to Kelsey (2019).[44] That report goes on to relate ecological forestry and reduced high severity fires with better air quality, water quality, carbon storage, and wildlife habitat.

Fire crews conducting controlled burns at the Independence Lake Preserve which provides water for Reno and western Nevada. © Ed Smith/TNC

43 Clark, S.A., Miller, A., and Hankins, D.L. 2021. Good Fire: Current Barriers to the Expansion of Cultural Burning and Prescribed Fire in California and Recommended Solutions. Karuk Tribe, California. https://karuktribeclimatechangeprojects.files.wordpress.com/2021/03/karuk-prescribed-fire-rpt_final-1.pdf

44 Kelsey, R. 2019. Wildfires and Forest Resilience: the case for ecological forestry in the Sierra Nevada. Sacramento, California, The Nature Conservancy. https://www.scienceforconservation.org/products/wildfires-and-forest-resilience

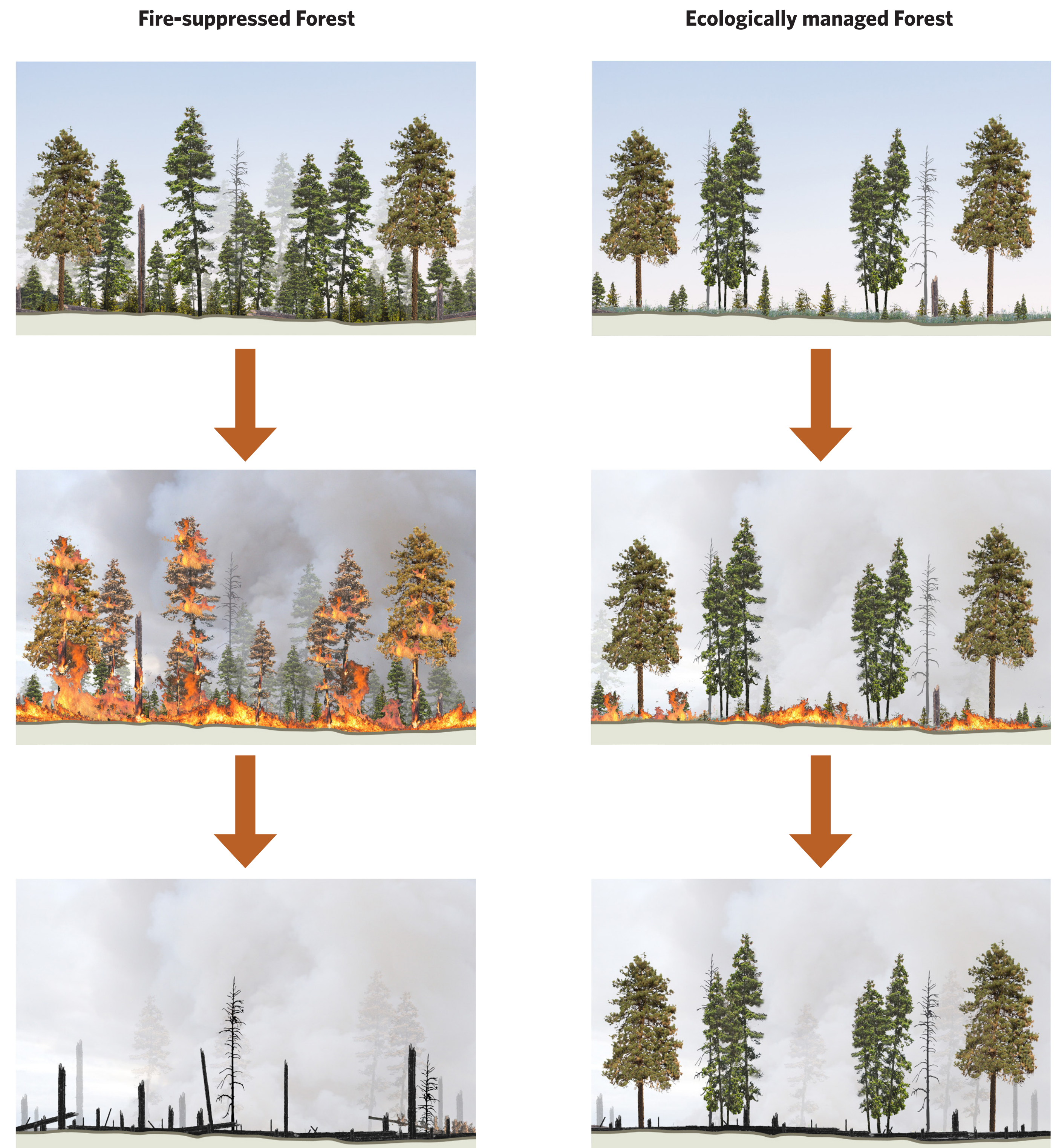


Figure 1-7. Ecological Managed Forests. By thinning the forest understory, we can safely reintroduce fire as a restorative process. Fire suppressed forest on the left. Ecologically thinned forest on the right. © Erica Simek Sloniker/TNC.[45]

45 Kelsey, R. 2019. Wildfires and Forest Resilience: the case for ecological forestry in the Sierra Nevada. Sacramento, California: Unpublished report of The Nature Conservancy. https://www.scienceforconservation.org/products/wildfires-and-forest-resilience

TNC is working with partners on the French Meadows Restoration Project to carry out ecological forestry at scale. © David Edelson/TNC

Section 2: French Meadows Project: Test Case Analysing Insurance Benefits of Ecological Forestry

In order to analyze whether the wildfire risk reduction benefits of ecological forestry practices can be accounted for in insurance modeling and structuring, we used an actual landscape scale ecological forestry project - the French Meadows Project - as the "test bed" to analyze and quantify insurance benefits of ecological forestry.

The French Meadows project[46] was catalyzed by the devastating 2014 King Fire that burned almost 100,000 acres on the Eldorado National Forest and on private timberlands. About 50% of the total fire acreage area sustained high severity burn, with 90% tree mortality or more. The King Fire required about 8,000 personnel to suppress and took a month and $117 million to be entirely suppressed.[47]

The French Meadows Project is a landscape scale ecological forestry project in largely national forest lands in Placer County, California, in the western foothills of the Sierra Nevada. The total project area consists of 28,000 acres, mostly within the Tahoe National Forest. The project is within the North Fork American River sub-basin, the watershed of the Placer County Water Agency, which is a water supply and hydro power generating agency. The project is a partnership between The Nature Conservancy, the United States Forest Service, the Placer County Water Agency, the County of Placer, the Sierra Nevada Research Institute of the University of California Merced, and the American River Conservancy. The project involves 12,183 acres of forest treatment within the total project area, using prescribed burning and thinning to restore forest

46 Smith, E. 2018. Tahoe National Forest, American River Ranger District French Meadows Project. Fire & Fuels Specialist Report. Sacramento, California, The Nature Conservancy.
47 USDA King Fire BAER fact sheet. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd566026.pdf

health, to reduce surface and ladder fuels, and to thereby reduce the severity of wildfire risk.

The French Meadows Project has already made important contributions in areas such as its partnership model, stakeholder management, project design and use of data models, and cost sharing. The Project's ecological forest treatment strategies are designed to create forest stand conditions where the reintroduction of frequent, low intensity fires that maintain open, fire resilient stands of trees is possible.

Fire behavior modeling was undertaken for the French Meadows Project. The fire behavior modeling demonstrated that the ecological forest treatments of the French Meadows Project would significantly reduce the severity of wildfire in and around the project area.

This study involved taking the French Meadows Project fire behavior modeling results and applying them within an insurance wildfire risk model to determine and quantify the insurance benefits of ecological forestry. The Placer County Water Agency and its assets were used to analyze the extent to which accounting for ecological forestry in indemnity and parametric insurance products for a water agency would lower expected losses and provide premium savings as a result.

2.1 Placer Water County Agency (PCWA) Assets: Analyzing Insurance Benefits

The Placer Water County Agency (PCWA) is a publicly owned and operated water and power utility with assets worth hundreds of millions of dollars in Placer County, including large industrial assets, such as power and water supply assets (e.g., dams, tunnels, reservoirs, spillways, water tanks), and buildings (e.g., dormitories, offices, shops, site buildings, etc.). PCWA also has financial responsibility for recreational facilities, though these are of relatively low value and are not further considered in our analysis. The Agency does not own power transmission lines, which are typically highly exposed to wildfire risk.[48]

The study first considered whether accounting for the risk reduction benefit of ecological forestry, as captured in indemnity property insurance for PCWA assets, would result in lower future estimated premiums.[49] Figure 2-1 shows that the only PCWA locations that are in or near the treatment area in the French Meadows Project are the French Meadows Dam, the French Meadows Spillway, and the French Meadows Tunnel. These structures, given the materials used for their construction, have low to very low vulnerability to damage from wildfire. Such structures are heavily dominated by values that are not generally priced for insurance with a view to their wildfire exposure as it is viewed as being significantly small or non-existent.[50] While buildings that can be vulnerable to wildfire risk are part of those structures, their insured values at risk is only around 0.2% of the total. Even if the savings to the physical damage of the buildings due to ecological forestry management was 100%, an insurer is almost certainly not going to adjust pricing for what is perceived to be little or no change in the overall risk posed to these structures.

For purposes of this analysis, therefore, we expanded the study area to the entire Placer County watershed in order to quantify the insurance impact of ecological-forestry management. (Figure 2-2). We recognize that performing ecological forestry in the entire watershed is not currently planned and the results should therefore be taken as an upper boundary. Having said that, the literature suggests that fuel treatments on approximately 30% of a watershed reduce the overall fire risk (burn probability) for the whole watershed (Buckley et. al., 2014).[51] Therefore, the actual treament area would only need to be one third of what it is shown in blue in the map of Figure 2-2 (assuming the treatment area was selected to maximize the total watershed area benefiting from the wildfire reduction outcome).

48 https://www.power-grid.com/2020/10/12/wildfire-impacts-and-californias-energy-supply/
49 As the benefits accruing from ecological forestry will only apply to future insurance premiums, we can only estimate future pricing, based on an assumption that the relationship between technical risk and premium price will remain similar to what it has been in the recent past.
50 https://www.statesmanjournal.com/story/news/2020/09/13/detroit-big-cliff-dams-intact-beachie-creek-fire-oregon/5787321002/
51 Buckley, M., Beck, N., Bowden, P., Miller, M., Hill, B., Luce, C., Elliot, W., Enstice, N., Wilson, K., Winford, E., and Smith, S.L. 2014. Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense. Sacramento, California, Sierra Nevada Conservancy.

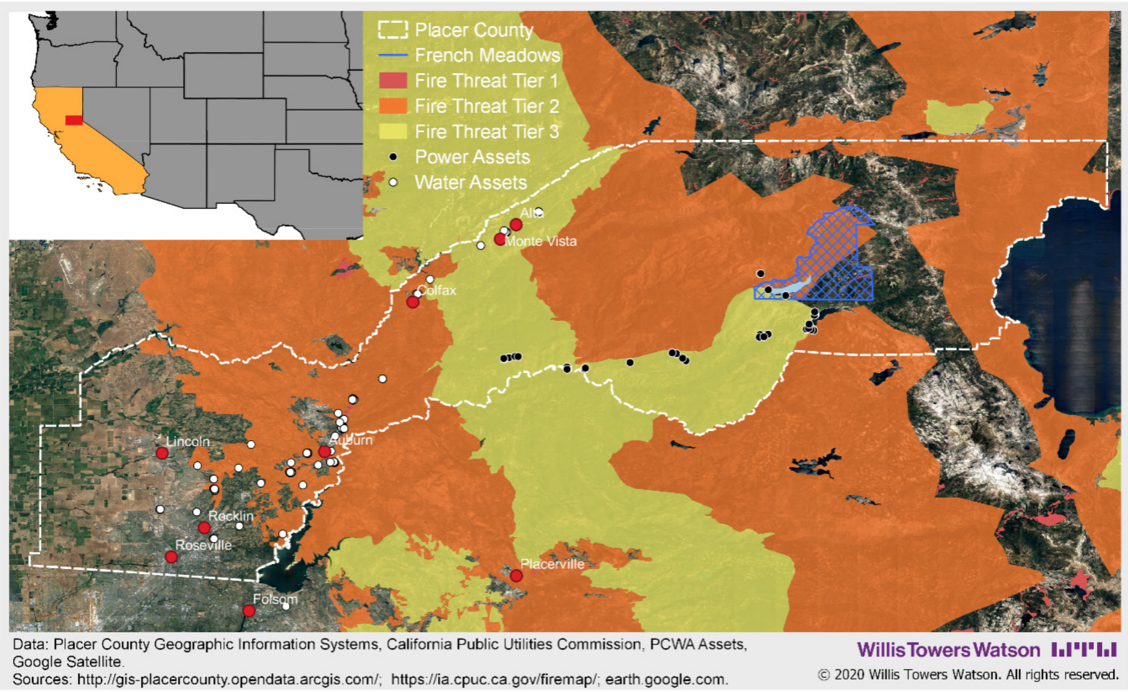


Figure 2-1. Site map annotated with Placer County Administrative Boundary, French Meadows conservation area, PCWA assets, fire threat tiers, and selected settlements.

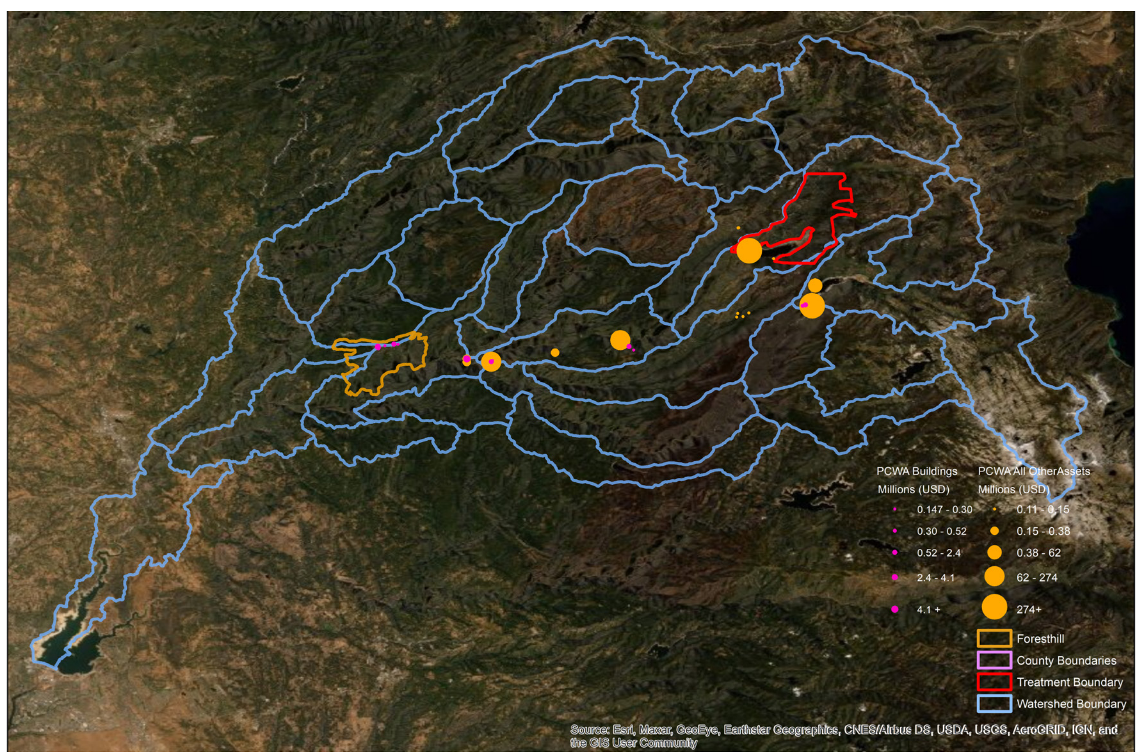


Figure 2-2. Placer County boundary shown in purple, the North Fork American River sub-basin and constituent Watersheds in blue, the French Meadows treatment area in red, and Foresthill settlement in orange. PCWA properties are shown with bubbles, bubble size representing value at risk as provided by PCWA. The industrial properties are indicated in orange and the small commercial property (i.e., the buildings) in pink.

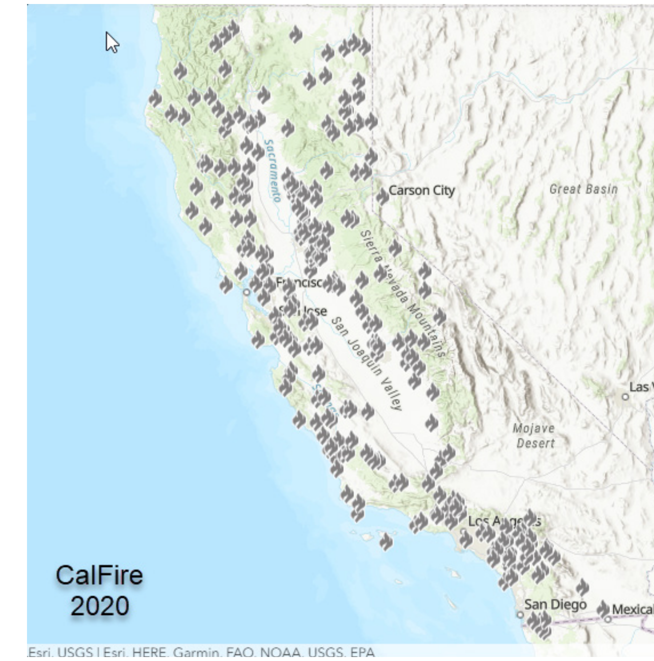
2.2 Residential Property Portfolio: Analyzing Insurance Benefits of Ecological Forestry

Over the past decade, the severity and scope of the wildfires in California, their proximity to populated areas, and the risks that they pose to the state's electric supply have increased significantly. The 2020 wildfire season in California broke records for the total amount of acreage burned. CalFire reports over four million acres burned throughout the state, more than nine thousand incidents, 31 fatalities, and more than ten thousand structures damaged.

These fires threaten both communities and natural resources, as perhaps most starkly demonstrated by the 2018 Camp Fire, which burned nearly 19,000 structures, killed 86 people, and resulted in insured losses of $12 billion.

Given the destruction and damage to residential structures from wildfires and associated residential insurance losses, we analyze the economic impacts of ecological forestry and quantify the insurance savings for a representative residential property portfolio. We use the building stock distribution and insured value of residential locations from the Pitney Bowes[52] US Address Fabric with the Property Attribute Data. The total annual premium analyzed is over $51 million for 81,620 residential structures. The premium estimation and details on this portfolio are provided in the next section along with the results of our analysis.

Additionally, we examine what insurance premium savings for homeowners could potentially be achieved if the French Meadows Project was undertaken in an area adjacent to and therefore benefiting (in terms of wildfire risk reduction) residential structures. We chose the Foresthill community for this analysis as it is entirely within the watershed[53] (see Figure 2-2 denoted in orange) and is of a size that is a reasonable representation of a residential property insurance portfolio.



Summary of all 2020 wildfire incidents in California, including those managed by the California Department of Forestry and Fire Protection (CAL FIRE) and other partner agencies. A total of 9,917 incidents burned over 4.26 million acres, damaged or destroyed 10, 488 structures and claimed 33 lives (https://www.fire.ca.gov/incidents/2020/).

We caution that determining where and how to apply ecological forestry treatment requires expert consideration of a variety of factors beyond the scope of this report. The goal of the watershed and Foresthill treatment scenarios is solely to demonstrate the potential insurance savings that could be reasonably expected if the wildfire risk reduction outcomes resulting from the French Meadows' project were extrapolated, strategically, to other regions within the watershed that included significant residential property.

52 https://www.pitneybowes.com/us

53 This is a theoretical study conducted by Willis Towers Watson in order to test the potential savings in insurance premiums. We have no knowledge of whether ecological forestry management could actually be performed in and around Foresthill from a natural science perspective, the costs associated with it, or how efficient that would be in reducing risk.

California's 2014 King Fire burned 97,000 acres including portions of PCWA watershed. © Pacific Southwest Forest Service/Creative Commons

Section 3: Indemnity Wildfire Resilience Insurance: Analysis of Ecological Forestry Benefits

In this section, we detail the methodology followed to model the effect of ecological forestry practices on wildfire risk as assessed within an insurance industry modeling environment and its impact on indemnity insurance risk and pricing analytics. The fire-behavior analysis contained in the French Meadows "Fire & Fuels Specialist Report" (Smith, 2018[54], hereinafter referenced as French Meadows FFSR), a wildfire event set provided by the U.S. Forestry Service (Karen Short, USFS, personal communication, 2020), and the Willis Re Wildfire Risk Score Model (Appendix A), are combined analytically to quantify the insurance savings for structures in and around the watershed at Placer County.

For purposes of this analysis we assume that ecological forestry treatment is undertaken at a large enough scale so that the entire PCWA watershed sees wildfire hazard reduction benefits (i.e., 30% of the watershed treated provides wildfire hazard reduction benefits across the watershed as per Buckley et al., 2014[55]). We also estimate the annual home insurance premium for a residential portofolio with more than 80,000 structures reduces from $51 million to $30 million, or 40%. The industrial power and water assets from PCWA are generally not vulnerable to wildfire physical damange and therefore see no measurable reduction. However, buildings which are vulnerable to fire owned by PCWA see a reduction of 44% in their annual indemnity insurance premium on average, ranging from 10% up to 84%, depending on their location.

54 Smith, E. 2018. Tahoe National Forest, American River Ranger District French Meadows Project. Fire & Fuels Specialist Report. Sacramento, California, The Nature Conservancy.
55 Buckley, M., Beck, N., Bowden, P., Miller, M., Hill, B., Luce, C., Elliot, W., Enstice, N., Wilson, K., Winford, E., and Smith, S.L. 2014. Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense. Sacramento, California, Sierra Nevada Conservancy.

3.1 Modeling Methodology

The Willis Re Wildfire Score is a risk ranking tool used by a number of insurers in the state of California for the purpose of risk selection and rate making. The tool has been filed successfully with the California Department of Insurance for both purposes, and it is an accepted and implemented risk ranking tool for insurers underwriting wildfire risk. It serves as a good indicator for understanding how insurers might view wildfire risk in the study area and how that view may change due to ecological forestry management.

The score uses data from the U.S. Forestry Service Fire Simulation System (FSIM) model[56] in its computation of the risk that a vegetated stand poses to nearby property. FSIM is designed to simulate the occurrence of wildfires under tens of thousands of hypothetical fire seasons to estimate the probability of a given area burning (Finney et al., 2011).[57] The output of the model is a grid of the total annual probability of each cell burning and six contingent probability grids that represent the likelihood, given a fire has occurred, that it falls within the flame length class of the respective band. The Willis Re model then combines the bands into a score, referred to as the Large Wildfire Potential (LWP), in a method closely but not entirely following Dillon et al. (2015)[58] (see Appendix A). This value is the primary determinant of the contribution that a nearby forest has on the final wildfire score value for a given structure.

The most rigorous approach to represent the impact of ecological forestry on insurance premium using the Willis Re model would be to remodel the output of FSIM to appropriately capture the changes in vegetation type. For the purposes of this study, however, the model is adjusted more pragmatically to account for effects like mitigation, urban development etc., following the findings from the French Meadows FFSR, which was part of the environmental assessment undertaken for the project. The Fire and Fuels report details the change in exceedance probability of fires greater than four and eight feet in flame length due to the French Meadows Project ecological forestry treatment of forest lands in the project area.

The equation that combines the bands to compute the large wildfire potential (LWP) is as follows:

Equation 1

$$LWP = (FIL_1 \times ABP \times W_1) + (FIL_2 \times ABP \times W_2) + (FIL_3 \times ABP \times W_3) + (FIL_4 \times ABP \times W_4)$$

Where:
FIL_1 = contingent probability of flame length band: 0 – 4 feet;
FIL_2 = contingent probability of flame length band: 4 – 8 feet;
FIL_3 = contingent probability of flame length band: 8 – 12 feet;
FIL_4 = contingent probability of flame length band: >12 feet;
ABP = annualized probability of any fire occurring;
Wi = Resistance to Control Weights ($W_1 = 1$, $W_2 = 8$, $W_3 = 25$, $W_4 = 75$).

The Resistance to Control Weights are based on the fire line intensity generated by the average flame length in each band and normalized to the Fireline Intensity in FIL_1 (see Appendix A, Table A-1 for more detail).

The French Meadows FFSR finds that with ecological forest treatment about 60% of wildfires with a flame length greater than 8 feet were reduced to fires of lower flame length. Equation 1 is modified in order to represent the magnitude of the ecological forestry impact on wildfire behavior as follows:

Equation 2

$$LWP_2 = (FIL_1 \times ABP \times W_1) + (FIL_2 \times ABP \times W_2) + (FIL_3 \times ABP \times W_2 \times 0.6) + (FIL_3 \times ABP \times W_3 \times 0.4) + (FIL_4 \times ABP \times W_2 \times 0.6) + (FIL_4 \times ABP \times W_4 \times 0.4)$$

This equation modifies the large wildfire potential so that 60% of the flame length band 8 to 12 feet (FIL_3) is seen in the 4 to 8 feet band (FIL_2), and 60% of >12 feet flame lengthlength fires are seen in the 8 to 12 feet band.

56 Short, K.C., Finney, M.A., Vogler, K.C., Scott, J.H., Gilbertson-Day, J.W., and Grenfell, I.C. 2020. Spatial datasets of probabilistic wildfire risk components for the United States (270m). 2nd Edition. Fort Collins, Colorado, Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2016-0034-2
57 Finney, M.A., McHugh, C.W., Grenfell, I.C., Riley, K.L., and Short, K.C. 2011. A simulation of probabilistic wildfire risk components for the continental United States. Stochastic Environmental Research and Risk Assessment. 25: 973-1000.
58 Dillon, G.K., Menakis, J., and Fay, F. 2015. Wildland fire potential: A tool for assessing wildfire risk and fuels management needs. In: Keane, R.E., Jolly, M., Parsons, R., and Riley, K. Proceedings of the large wildland fires conference; May 19-23, 2014; Missoula, MT. Proc. RMRS-P-73. Fort Collins, Colorado, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 60-76.

Modified LWP grids can be built-in and computed in the model, allowing us to investigate changes in expected loss and, therefore, expectations of future premium for different amounts of treated area within the watershed. Figure 3-1 shows the comparison between wildfire hazard without (Figure 3-1a) and with (Figure 3-1b) ecological forestry treatment for the watershed. It is important to note that the literature suggests that fuel treatments on approximately 30% of a watershed reduce the overall fire risk (burn probability) for the whole watershed (Buckley et al., 2014).[59]

The modeling conducted in this study, incorporates wildfire behavior modeling and research, and translates it into quantification of hazard that the risk-score model can understand and process. It is not a physical / biological model that would respond to actual ecological forestry treatment. Thus, the entire watershed has to be modified in the catastrophe model to represent the response of the entire watershed. Which specific areas would be actually treated is the purview of experts in the application of ecological forest treatment and beyond the scope of this study. The economic results from our work in the entire watershed should be compared to the investment necessary to treat potentially as little as 30% of the watershed, as per Buckley et al. (2014).[60]

3.2 Ecological Forestry Insurance Impact for PCWA and a Representative Residential Portfolio

For the purpose of computing the estimated home insurance premium for the representative residential portfolio distribution, industry data and publicly available filings on rating methodologies are used. While the complexities and dynamics of the ways that individual insurers underwrite and compete with one another cannot be easily captured, a very broad sense of the magnitude of change can be estimated with the following approach. The first element is to determine the typical cost of homeowner insurance in this area. Using data available from the California Department of Insurance, we determined the rate per $100,000 of building coverage to be approximately $300. Statewide, the proportion of the premium that is driven by wildfire risk is typically estimated to be about 50%, a conservative estimate in a region such as this one where it is likely higher.

When filing a risk score model with the California Department of Insurance, the expectation is that an insurer will be able to demonstrate how the score correlates to losses, such that the relative riskiness of each risk score band can be demonstrated and implemented. For the purpose of this study we have relied on Willis Re-developed relativities, based on historical losses and the underlying frequency outputs of FSIM. Using these relativities, the proportion of the premium allocated to wildfire can be scaled relative to the individual location's wildfire score.

One aspect of the Willis Re risk score model to note is that it can be influenced by vegetation up to five km from a given location. Therefore, at the boundaries of the watershed, the hazard there can still impact homes that are five km from the watershed boundary. As a result, the residential analysis incorporates all properties that are inside the watershed boundary, plus residences within five km of it, as shown in Figure 3-2.

The impact of ecological forestry treatment across the watershed on a residential portfolio as described above, and in the previous section and as shown in Figure 3-2, is to reduce the aggregate premium, on average, by 41% (over $21 million a year, Table 3-1). Since a large reduction in severe (high flame length) wildfires eliminates many of the wildfires that are the most difficult to suppress, and therefore most likely to cause damage to residential property, the results are consistent with what would be expected.

In addition, we analyzed the risk reduction benefit of ecological forest treatment on home insurance premiums for a smaller community within the watershed – the Foresthill community. The aggregate home insurance premium savings was 52% for the 533 homes in the Foresthill community (Figure 3-1).

59 Buckley, M., Beck, N., Bowden, P., Miller, M., Hill, B., Luce, C., Elliot, W., Enstice, N., Wilson, K., Winford, E., and Smith, S.L. 2014. Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense. Sacramento, California, Sierra Nevada Conservancy.

60 Buckley, M., Beck, N., Bowden, P., Miller, M., Hill, B., Luce, C., Elliot, W., Enstice, N., Wilson, K., Winford, E., and Smith, S.L. 2014. Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense. Sacramento, California, Sierra Nevada Conservancy.

(a)

(b)

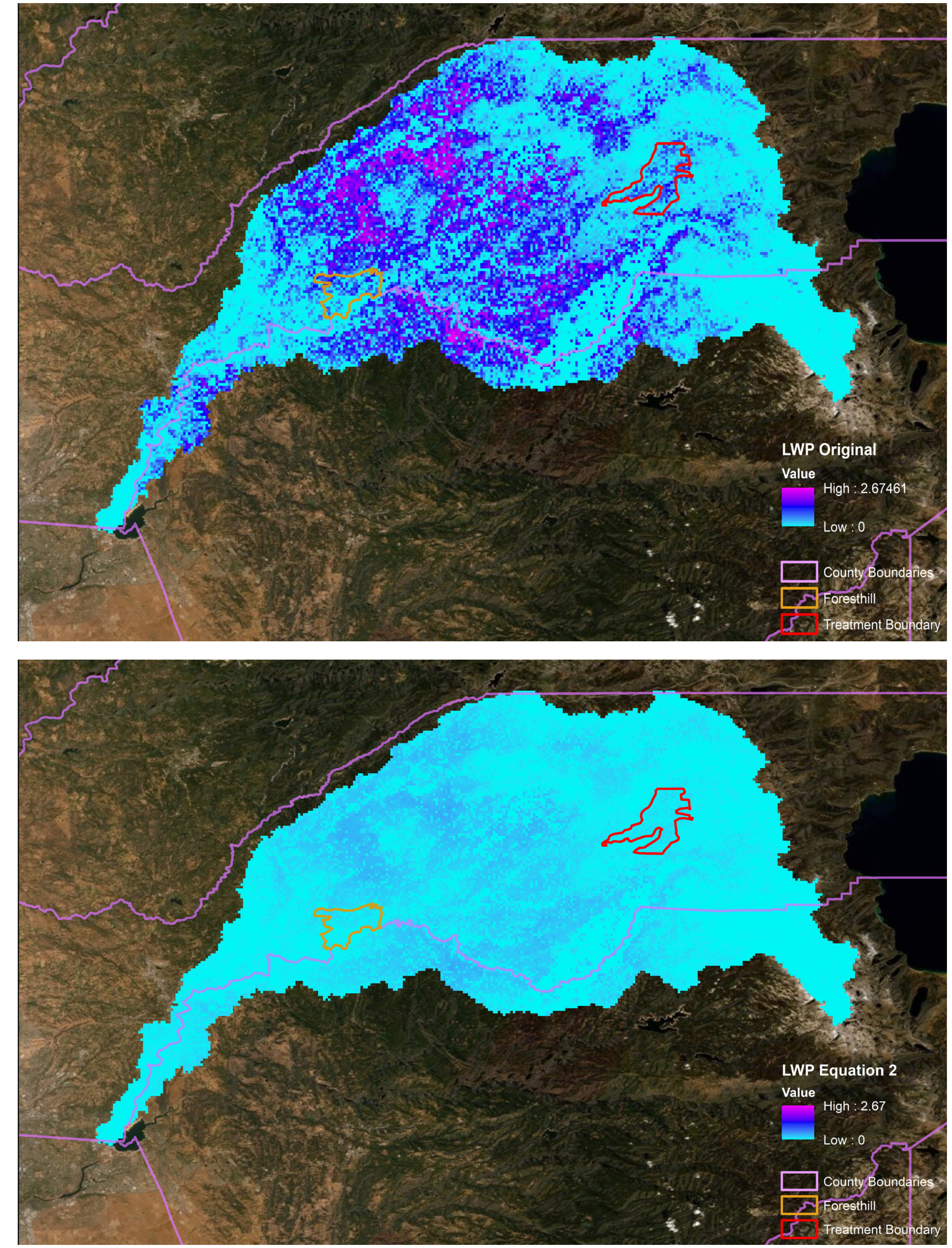


Figure 3-1. Wildfire hazard (i.e., Willis Re wildfire risk-scores) for the model without (a) and with ecological forestry management (b), for the North Fork American River sub-basin. Shown in purple is the Placer County boundary, in red the French Meadows treatment area, and in orange is Foresthill community.

Table 3-1. Change in estimated premiums for residential properties and percentage of premium reduction due to ecological forestry management in the watershed and Foresthill community for the distribution shown in Figure 3-2.

Area Impacted	Premium, no ecological forestry	Number of residential structures	Average Premium	Premium with ecological forestry treatment	
				Value	% reduction
Watershed	$51,094,726	81,620	$626	$29,965,430	**41%**
Foresthill	$870,470	533	$1,633	$416,495	**52%**

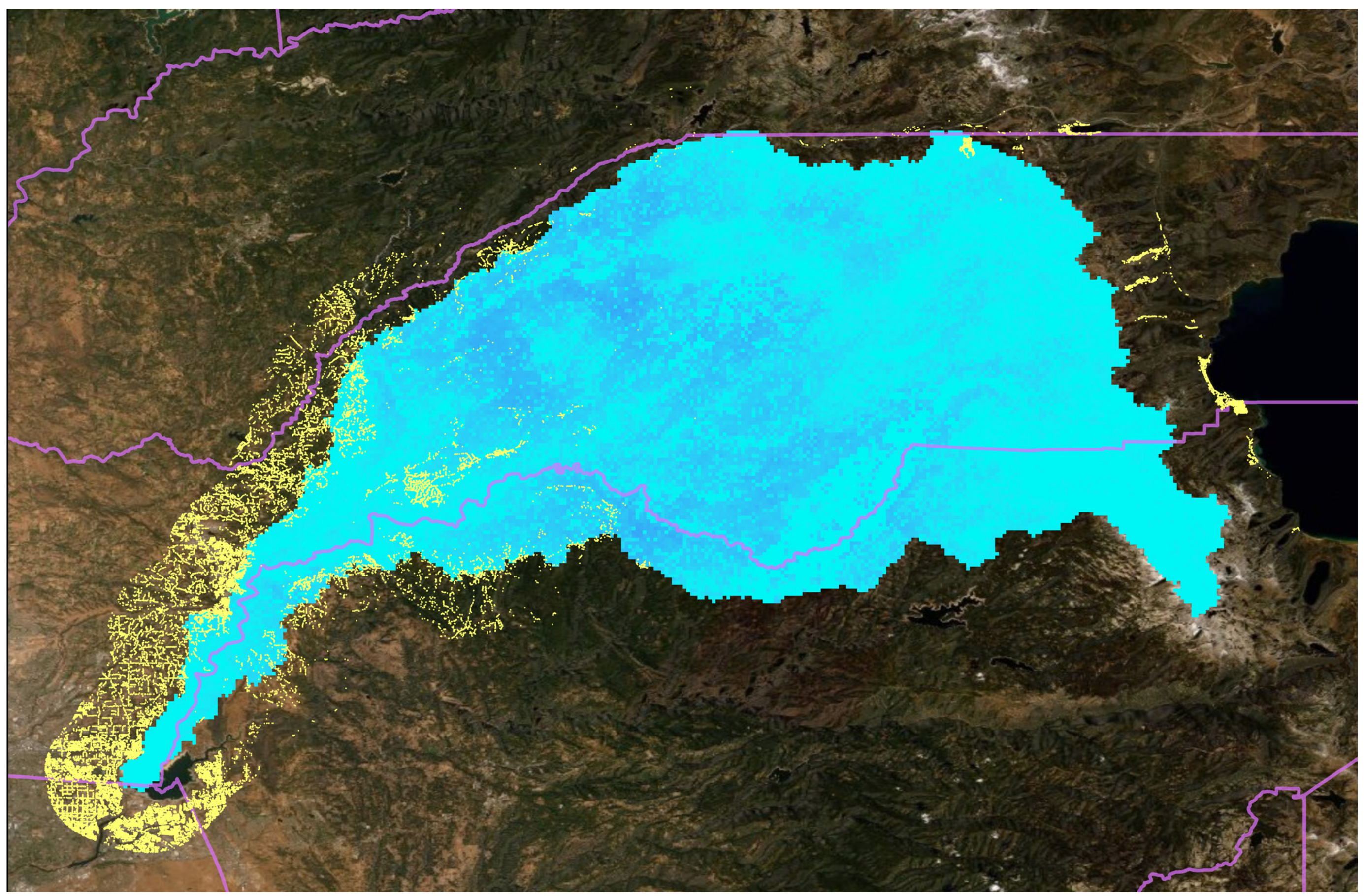


Figure 3-2. The blue colors denote the North Fork American River sub-basin and in yellow are the residences affected by changes in risk scores in and around the watershed (i.e., within the five km buffer which was created).

Figure 3-3 shows the difference in the distribution of residential premiums between the model with (blue) and without (pink) ecological forestry. While there is an overall decrease in premiums at all levels, there is a larger shift in the reduction of the highest premiums, which corresponds with a reduction in the frequency of the most intense fires. This explains in part the relatively larger premium reduction in the Foresthill region, which has higher premiums on average than properties in and adjacent to the whole watershed. Additionally, Foresthill is almost entirely in an intermixed zone for wildfire risk. The analysis in the entire watershed and residences within five km from its limit are affected by its forests, including risks that are in the intermixed zone, are within the WUI and in urban areas. As risks become more urban, the impact of the change in fire regime impacts their overall risk less than areas that are heavily forested.

As previously discussed, the PCWA's large industrial assets, which make up most of their insured assets, have only very low vulnerability to wildfire. Its buildings, however, are vulnerable to wildfire and we estimated the changes in annual average loss (AAL) associated with ecological forestry for those buildings. As previously noted, premium is proportional to the AAL and therefore it is a good metric to assess the insurance benefits of ecological forestry management.

On average, the reduction on expected loss for the PCWA buildings is 44%, with a minimum reduction of 10% and a maximum reduction of 84% for a total of 13 assets analyzed in the watershed, and a total of $22.7 million of values at risk. The properties that pay a higher premium relative to their value at risk are the ones that benefit from the greatest reductions.

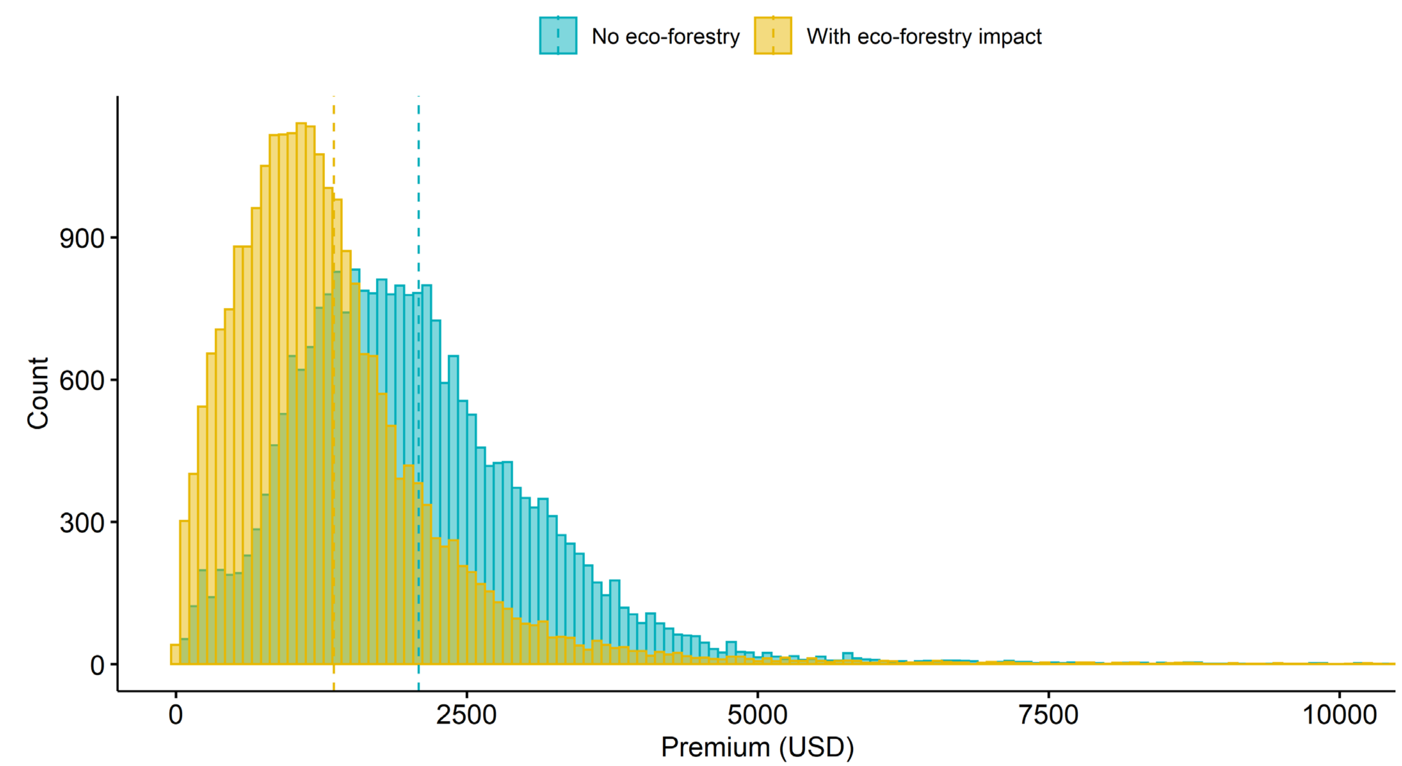


Figure 3-3. Distribution of change in premium in the properties affected by ecological forestry impacts on the watershed versus the standard model.

2018 Campfire took 86 lives and destroyed 11,000 homes, including most of the Town of Paradise, California. © Senior Airman Crystal Housman, California National Guard/ Creative Commons

Section 4: Parametric Wildfire Insurance Coverage

Parametric insurance for wildfire is an established product in the global catastrophe risk marketplace, although its deployment has been quite limited to date. To our knowledge, it has not been deployed to cover wildfire risk in the northern Sierra Nevada, nor to cover the risk of wildfire as it impacts an agency like PCWA. However, interest in parametric insurance for wildfire in California, as well as globally, is growing quickly, as the risk level becomes more apparent and as traditional forms of indemnity insurance are found to be unsuitable and/or unaffordable.

There are several reasons, summarized below, why parametric insurance is a useful lens through which to explore wildfire hazard and risk, and ecological forestry impacts on that hazard and risk.

1) Parametric insurance deals directly with the frequency and severity of hazard, and the fundamental value proposition of parametric insurance (premium cost vs future pay-outs) is unaltered by considerations of exposure and vulnerability. This is not to say that exposure and vulnerability are ignored – both are critical inputs to the design of a particular parametric cover for a particular client — but once decided, these factors are locked into the parametric risk transfer contract and it is then the hazard alone that drives the pay-out behavior. So, changes in hazard feed directly through to changes in the risk profile of the parametric contract, and therefore to pricing of that contract. It is worth noting, again, that ecological forestry is unique as a risk management strategy as it impacts on natural catastrophe hazard, rather than on exposure or vulnerability, which are the usual foci of risk reduction approaches for natural catastrophes.

2) Parametric contracts are flexible in terms of the scale of coverage — so that they can reflect diverse risk over a wide area and are not tied to the fixed value of an asset or portfolio of assets. This means that they are particularly suited to covering wildfire risks beyond just the value of destroyed trees (though this is possible), such as the additional cost of operating after a wildfire has affected an area of forest, or the loss of revenue generated from use of the forest area (e.g., for recreational purposes).

3) Proceeds from parametric contracts are also flexible in the way that they can be used — something that is not particularly relevant for a home or business owner in the wildland urban interface (WUI), who wishes to have coverage to replace destroyed — or to repair — damaged property. It is, however, highly relevant to an entity, such as PCWA, that has wildlands as the backdrop to most of its business activities. In a given fire, the impacts on such an entity can be diverse and some, at least, unforeseeable. So, flexibility in deployment of pay-outs can be extremely valuable.

4) Parametric contracts pay out — or can pay out — very quickly. So, in circumstances where liquidity is a factor and speed is of the essence, parametric coverages can add great value.

4.1 Product Development

Significant analytical innovation was required in order to fully explore the particular case of French Meadows and the ecological forestry project there (i.e., building on wildfire frequency / severity modeling which quantified the ecological forestry benefits in the French Meadows FFSR), develop the use-cases for PCWA and beyond relevant to the French Meadows area and, importantly, document an analytical approach and product structures which could be applied broadly across the western US.

Key inputs to our analytical approach[61] are historical fire activity characteristics (e.g., fire frequency, area burned per fire, and differential burn severity within fire footprints), accounting for climate change and relative changes to these characteristics due to ecological forestry. These characteristics are adjusted for the area with ecological forestry management and for a larger, surrounding area that is assumed to benefit from ecological forestry. We call the area that is not treated, but benefits from ecological forestry, the "buffer zone". This buffer zone is important to capture, as it amounts to an area more than double the treated area (Buckley, et al., 2014). Within the buffer zone, fires are assumed to have similar characteristics to those fires that start within the ecological forestry area itself.

Another major innovation with this study is the creation of a "severity of burned area" parametric wildfire product to complement the simple burned area approach deployed in the global marketplace to date. Ecological forestry demonstrably reduces burn severity, so it was important to model and design a parametric wildfire insurance product which captures ecological forestry's reduction in severe wildfire risk. Capturing burn severity is important – not all forest fires are the same, nor is a single forest fire the same throughout. High-severity burns, taking place in the forest crown and affecting old-growth as well as younger trees and undergrowth, are more impactful and have impacts of longer duration than low-severity burns. The new product allows for differentiation between high- and low-severity burned areas, with differential per-acre compensation for each.

Structures for Parametric Wildfire Insurance

Most burned area indices are based on processing electromagnetic reflectance data from satellite sensors. As satellites orbit Earth, instruments onboard are capable of detecting and distinguishing electromagnetic radiation across the visible and spectrum and beyond. The important wavelengths of electromagnetic radiation to distinguish burned vegetation are the near-infrared (NIR) and short-wave infrared (SWIR). These specific wavelengths are important because burned vegetation has low reflectance in NIR and high reflectance in SWIR. However, healthy vegetation has the opposite reflectance, having high reflectance in NIR and low reflectance in SWIR. The difference between reflectance spectra of healthy vegetation and burned vegetation can be exploited to produce burn-sensitive "normalized burn ratio", also known as NBR (e.g., Eidenshink et al., 2007[62], Fernández-Manso et al., 2016[63], Chuvieco et al., 2019[64]).

61 Our analytical approach is one that does not require the use of a full set of wildfire event scenarios such as are produced in the US Forest Service's FSIM simulation model. Such simulations are specific to the forestry character of the area of interest, the scope of the ecological forestry treatment (if present in the area of interest), and to future climate change scenarios (if those are to be taken into account), and thus require substantial investment for each use case. Instead, we have developed an approach that requires certain assumptions to be made and which is parameterised based on those assumptions.

62 Eidenshink, J., Schwind, B., Brewer, K., Zhi-Liang, Z., Quayle, B., and Howard, S. 2007. A Project for Monitoring Trends in Burn Severity. Fire Ecology, 3, 3–21. https://doi.org/10.4996/fireecology.0301003

63 Fernández-Manso, A., Fernández-Manso, O., and Quintano, C. 2016. SENTINEL-2A red-edge spectral indices suitability for discriminating burn severity. International Journal of Applied Earth Observation and Geoinformation, Vol. 50, 170–175. https://doi.org/10.1016/j.jag.2016.03.005

64 Chuvieco, E., Mouillot, F., van der Werf, G.R., San Miguel, J., Tanase, M., Koutsias, N., García, M., Yebra, M., Padilla, M., Gitas, I., Heil, A., Hawbaker, T.J., and Giglio, L. 2019. Historical background and current developments for mapping burned area from satellite Earth observation. Remote Sensing of Environment, Vol. 225, 45-64. https://doi.org/10.1016/j.rse.2019.02.013

The NBR is calculated in equation 3.

Equation 3

$$NBR = \frac{\rho_{NIR} - \rho_{SWIR}}{\rho_{NIR} + \rho_{SWIR}}$$

Where:
'ρ' is the reflectance, between 0–1, at the considered wavelength.

The NBR of a forested area is generally negative before a fire and positive after a fire. The change in NBR can be exploited to determine burned areas, by calculating the difference in NBR before a fire (preNBR > 0) and NBR after a fire (postNBR < 0), to produce the dNBR as per equation 4.

Equation 4

$$dNBR = preNBR - postNBR$$

Thus, if dNBR is positive, then areas of vegetation have become burned.

Furthermore, dNBR is positively correlated with burn severity (Miller & Thode, 2007[65]), such that more severely burned regions can be separated from less severely burned regions. Burn severity can be further analyzed by considering the dNBR relative to pre-existing, background reflectivity, termed the RdNBR. Use of dNBR and/or RdNBR is the basis of many burned area (Tansey et al., 2008[66]; Giglio et al., 2018[67]; Boschetti et al., 2019[68]) and burn severity mapping algorithms (Eidenshink et al., 2007[69]; Miller & Thode, 2007[70]; Lutz et al., 2001[71]; Fernández-Manso et al., 2016[72]).

Burned Area Products

For standard burned area measurement from space, the NASA MODIS satellites (Terra and Aqua) generate the most robust data set, which has become the most commonly used in parametric insurance transactions. The MCD64A1 C6 algorithm is the most sophisticated algorithm using MODIS data at present and is used hereafter when referring to MODIS data (Giglio et al., 2018[73]; Boschetti et al., 2019[74]). The MODIS burned area index is open source and independently calculated by NASA. It extends back to November 2000 and an "archive" version is distributed each month, with a three-month lag. The outputs are 1,200 by 1,200 km tiles in a sinusoidal projection, with approximately 463 by 463 m pixels that are classified as burned, unburned, or unmapped (Boschetti et al., 2019[75]).

Figure 4-1 compares the final perimeter of the King Fire, a large 2014 fire, which impacted on the south-eastern part of Placer County, as mapped on the ground to the MODIS burned area footprint.

Although the MODIS burned area dataset has become the standard for parametric wildfire insurance, other burned area datasets are available for both historical analysis and real-time trigger calculation. NASA's Landsat data goes back to 1980, although most data is at lower spatial resolution than MODIS, while the Copernicus satellite array, launched by the European Space Agency (ESA) in 2014, includes Sentinel 2 which provides appropriate data at high spatial and temporal resolution.

65 Miller, J.D., and Thode, A.E. 2007. Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). Remote Sensing of Environment, Vol. 109, 66–80. https://doi.org/10.1016/j.rse.2006.12.006
66 Tansey, K., Grégoire, J.- M., Defourny, P., Leigh, R., Pekel, J.- F., van Bogaert, E., and Bartholomé, E. 2008. A new, global, multi- annual (2000–2007) burnt area product at 1 km resolution. Geophys. Res. Lett., 35, L01401. doi:10.1029/2007GL031567
67 Giglio, L., Boschetti, L., Roy, D.P., Humber, M.L., and Justice, C.O. 2018. The Collection 6 MODIS burned area mapping algorithm and product. Remote Sensing of Environment, Vol. 217, 72-85. https://doi.org/10.1016/j.rse.2018.08.005
68 Boschetti, L., Roy, D.P., Giglio, L., Huang, H., Zubkova, M., and Humber, M.L. 2019. Global validation of the collection 6 MODIS burned area product. Remote Sensing of Environment, Vol. 235, 111490. https://doi.org/10.1016/j.rse.2019.111490
69 Eidenshink, J., Schwind, B., Brewer, K., Zhi-Liang, Z., Quayle, B., and Howard, S. 2007. A Project for Monitoring Trends in Burn Severity. Fire Ecology, 3, 3–21. https://doi.org/10.4996/fireecology.0301003
70 Miller, J.D., and Thode, A.E. 2007. Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). Remote Sensing of Environment, Vol. 109, 66–80. https://doi.org/10.1016/j.rse.2006.12.006
71 Lutz, J.A., Key, C.H., Kolden, C.A., Kane, J.T., and van Wagtendonk, J.W. 2011. Fire Frequency, Area Burned, and Severity: A Quantitative Approach to Defining a Normal Fire Year. Fire Ecology, 7, 51–65. https://doi.org/10.4996/fireecology.0702051
72 Fernández-Manso, A., Fernández-Manso, O., and Quintano, C. 2016. SENTINEL-2A red-edge spectral indices suitability for discriminating burn severity. International Journal of Applied Earth Observation and Geoinformation, Vol. 50, 170–175. https://doi.org/10.1016/j.jag.2016.03.005
73 Giglio, L., Boschetti, L., Roy, D.P., Humber, M.L., and Justice, C.O. 2018. The Collection 6 MODIS burned area mapping algorithm and product. Remote Sensing of Environment, Vol. 217, 72-85. https://doi.org/10.1016/j.rse.2018.08.005
74 Boschetti, L., Roy, D.P., Giglio, L., Huang, H., Zubkova, M., and Humber, M.L. 2019. Global validation of the collection 6 MODIS burned area product. Remote Sensing of Environment, Vol. 235, 111490. https://doi.org/10.1016/j.rse.2019.111490
75 Boschetti, L., Roy, D.P., Giglio, L., Huang, H., Zubkova, M., and Humber, M.L. 2019. Global validation of the collection 6 MODIS burned area product. Remote Sensing of Environment, Vol. 235, 111490. https://doi.org/10.1016/j.rse.2019.111490

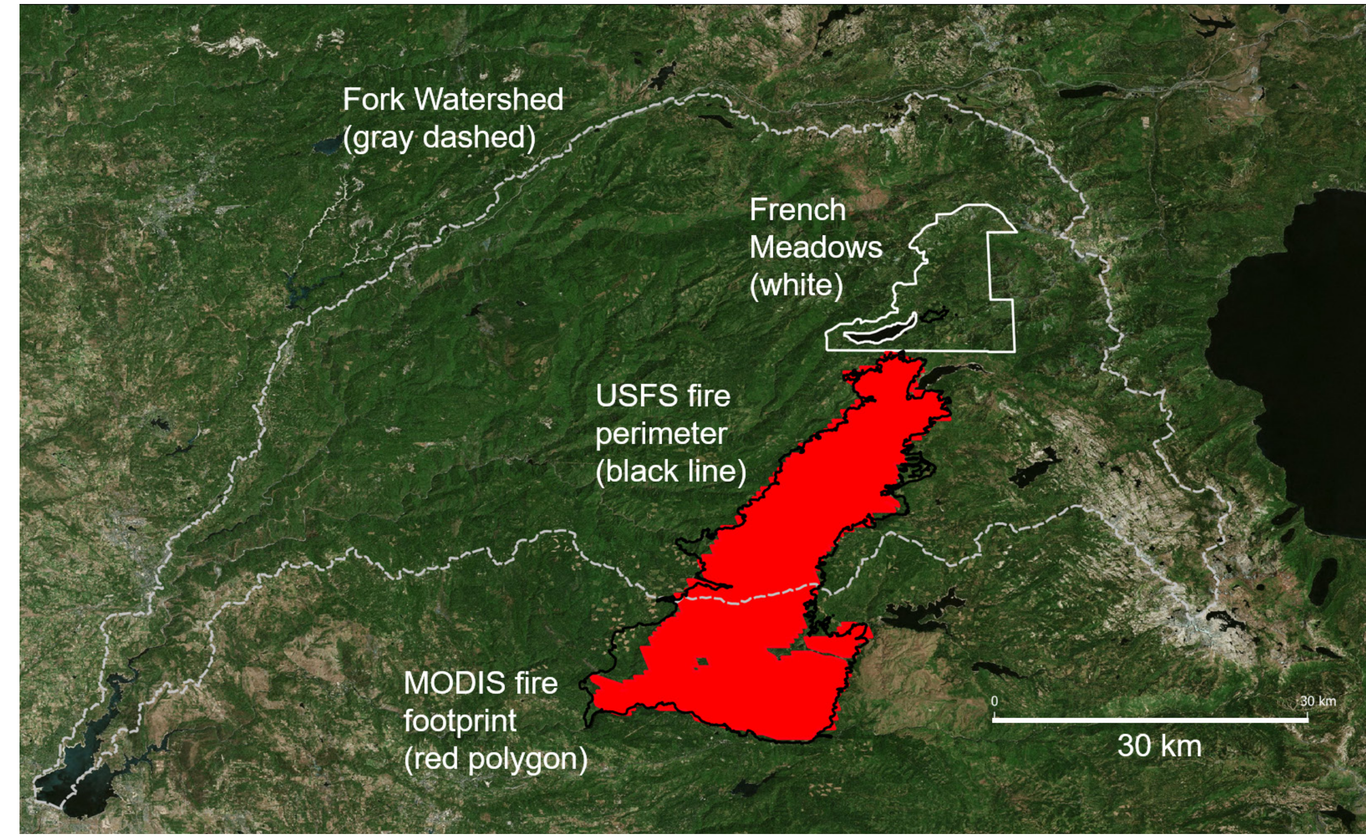


Figure 4-1. Comparison of ground-based fire perimeter and MODIS burned area footprint for the 2014 King Fire. The French Meadows project area (as per French Meadows FFSR, white) is shown within the North Fork American River sub-basin (grey dashed line).

Severity of Burned Area

As a basis for the new Severity of Burned Area product analytics, we have used the freely available fire perimeter and burn severity datasets from the Monitoring Trends in Burn Severity (MTBS) program that are based on Landsat data spanning 35 years. The MTBS datasets are based on expert assessment of histograms of dNBR and RdNBR, with four severity classifications for burned areas: unburned-low, low, moderate, and high severity (e.g., Figure 4-2a). Further information on the MTBS fundamental methodology is outlined in Eidenshink et al. (2007)[76] with recent updates to the MTBS method provided in Picotte et al. (2020)[77]. The MTBS datasets are available for fires larger than 1,000 acres (4 km2) in the western United States between 1984 and 2017, with interim data currently available for 2018 (as of 27 August 2020).

Figure 4-2 provides a summary of the MTBS dataset and its application to the French Meadows area (further described below).

While the MTBS dataset provides the best information for analyzing the historical distribution of burn severity, real-time trigger calculations could not rely on the full MTBS methodology because of the long lag in producing the final dataset for a given fire. Therefore, a stand-alone methodology is required which includes pre-defined differentiation between high-severity and low-severity burn areas based on purely quantitative information. Source data for the algorithm can be provided either by NASA's Landsat 8 satellite, or by ESA's Sentinel 2 satellite; the latter has higher temporal resolution, but both have similar spatial resolution and Landsat is preferred as it is the basis for the MTBS historical dataset.

76 Eidenshink, J., Schwind, B., Brewer, K., Zhi-Liang, Z., Quayle, B., and Howard, S. 2007. A Project for Monitoring Trends in Burn Severity. Fire Ecology, 3, 3–21. https://doi.org/10.4996/fireecology.0301003
77 Picotte, J.J., Bhattarai, K., Howard, D., Lecker, J., Epting, J., Quayle, B., Benson, N, and Nelson, K. 2020. Changes to the Monitoring Trends in Burn Severity program mapping production procedures and data products. Fire Ecology, 16, 16. https://doi.org/10.1186/s42408-020-00076-y

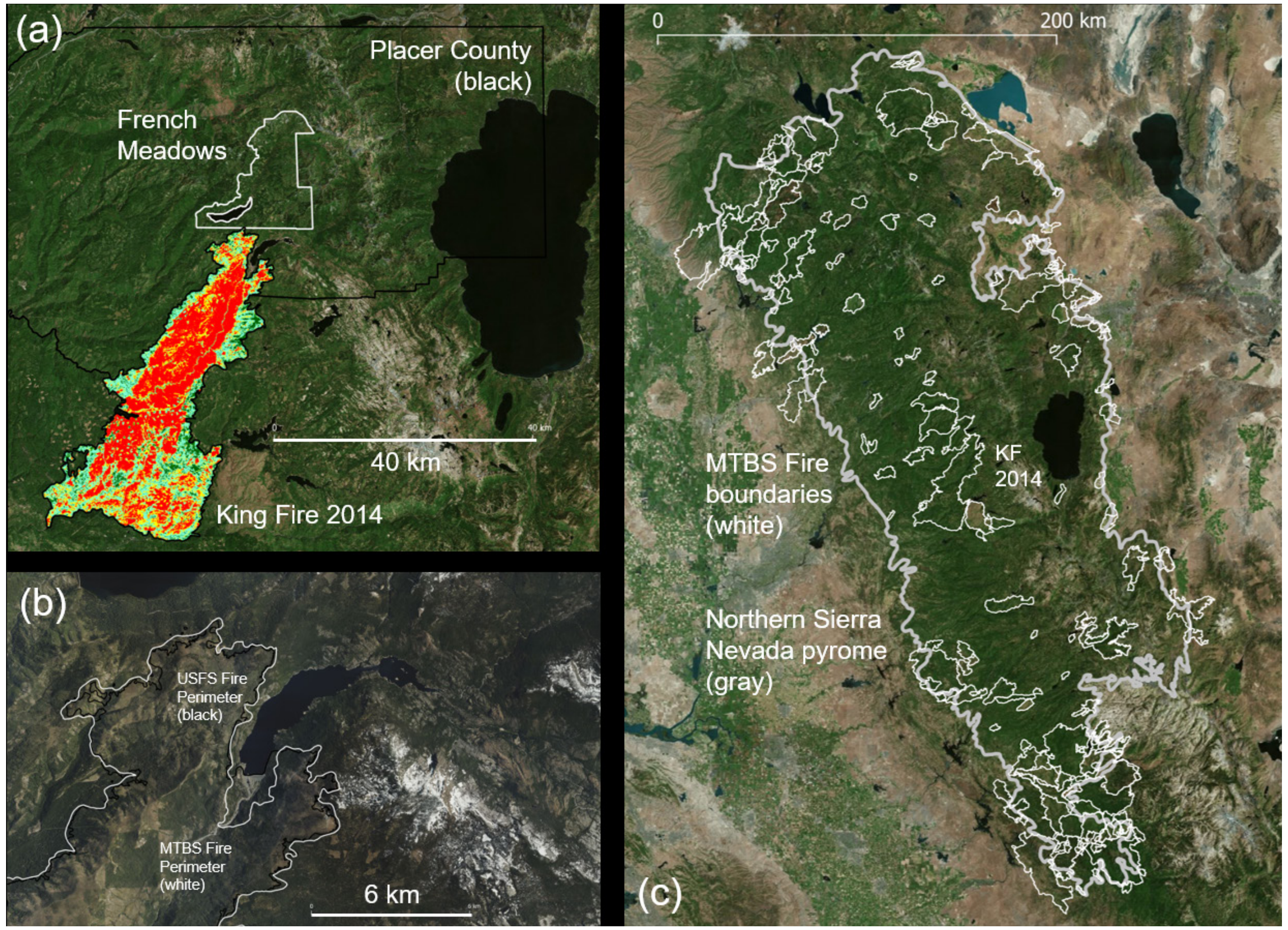


Figure 4-2. The fire severity and perimeters for the King Fire, 2014. (a) The MTBS severity classification (dark green = unburned-low, light green = low, yellow = medium, red = high) with the Placer County boundary (black) and French Meadows project area boundary (white). (b) A comparison between the MTBS fire perimeter (white) and the CalFire/USFS perimeter (black). (c) Northern Sierra Nevada Pyrome (grey thick line) with perimeters of the 156 fires between 1984 and 2018 that touch, intersect or are fully within the pyrome. The location of the King Fire is denoted by KF.

Historical Analysis for Eastern Placer County Area

In order to characterize the area and severity of fires in the relatively small French Meadows project area (approx. 50 km^2, Figure 4-1), we analyzed fires across a broader area (35,293 km^2) with similar fuel and vegetation classifications. This area has consistent fire characteristics (e.g., size, frequency) across the region and is referred to as the "North Sierra Nevada pyrome" (Short et al., 2020[78]; Figure 4-2c). This broader area spans 16 counties in California and Nevada. In total, 156 wildfires were extracted from the MTBS dataset that intersected with the Northern Sierra Nevada pyrome between 1984 and 2018 (Figure 4-2c). For quality control, the Motor Fire was removed from burn severity area analysis because 34% of data was missing.

Focusing on the North Sierra Nevada pyrome addresses several possible concerns in using MTBS products derived from satellite data, such as:

- MTBS severity classifications vary for similar fires in different locations (Kolden et al., 2015[79]). However, because we focus on similarly vegetated regions within a single pyrome, the severity of burned areas should be consistently classified using the MTBS method (Eidenshink et al., 2007[80]; Picotte et al., 2020[81]).

- Overlaps between low, moderate, and high severity classifications for similar dNBR values can lead to severity misclassification (Kolden et al., 2015[82]). In general, the dNBR MTBS threshold range in the Northern Sierra Nevada pyrome for "unburned-low" severity is between -100 and 100, "low" severity is between 100 and 200, "moderate" severity is between 200 and 400 and "high" severity is between 400 and 700 (Figure 4-3), although there are overlaps in threshold values. To ameliorate this issue, we cluster "unburned-low" and "low" severity MTBS classification to a simpler "low" classification, and the "moderate" and "high" severity MTBS classifications to a simpler "high" classification. Therefore, there should be less total area overlap between "low" and "high" classifications. We also note that there is less overlap of dNBR values between burn severity classifications in Northern California than most other regions in the US (Kolden et al., 2015[83]), suggesting the reasonableness of this approach in the Northern Sierra Nevada pyrome.

  We are also confident that MTBS burn severity appropriately reflects ecological burn severity. Recent analysis of MTBS burn severity products show good agreement with other measures of ecological damage (e.g., the Composite Burn Severity index) and field validation of tree mortality (Picotte et al., 2020[84]). Our method also addresses that high tree mortality (>60%) can occur with moderate and high MTBS classifications (Kolden et al., 2015[85]).

- Size of area so that burn history is representative. By using the entire Northern Sierra Nevada pyrome, our historical dataset is large enough to have high confidence in our assumptions used to parameterize our analytical model.

78 Short, K.C., Finney, M.A., Vogler, K.C., Scott, J.H., Gilbertson-Day, J.W., and Grenfell, I.C. 2020. Spatial datasets of probabilistic wildfire risk components for the United States (270m). 2nd Edition. Fort Collins, Colorado, Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2016-0034-2
79 Kolden, C.A., Smith, A.M.S., and Abatzoglou, J.T. 2015. Limitations and utilisation of Monitoring Trends in Burn Severity products for assessing wildfire severity in the USA. International Journal of Wildland Fire, 24, 1023-1028. https://doi.org/10.1071/WF15082
80 Eidenshink, J., Schwind, B., Brewer, K., Zhi-Liang, Z., Quayle, B., and Howard, S. 2007. A Project for Monitoring Trends in Burn Severity. Fire Ecology, 3, 3–21. https://doi.org/10.4996/fireecology.0301003
81 Picotte, J.J., Bhattarai, K., Howard, D., Lecker, J., Epting, J., Quayle, B., Benson, N, and Nelson, K. 2020. Changes to the Monitoring Trends in Burn Severity program mapping production procedures and data products. Fire Ecology, 16, 16. https://doi.org/10.1186/s42408-020-00076-y
82 Kolden, C.A., Smith, A.M.S., and Abatzoglou, J.T. 2015. Limitations and utilisation of Monitoring Trends in Burn Severity products for assessing wildfire severity in the USA. International Journal of Wildland Fire, 24, 1023-1028. https://doi.org/10.1071/WF15082
83 Kolden, C.A., Smith, A.M.S., and Abatzoglou, J.T. 2015. Limitations and utilisation of Monitoring Trends in Burn Severity products for assessing wildfire severity in the USA. International Journal of Wildland Fire, 24, 1023-1028. https://doi.org/10.1071/WF15082
84 Picotte, J.J., Bhattarai, K., Howard, D., Lecker, J., Epting, J., Quayle, B., Benson, N, and Nelson, K. 2020. Changes to the Monitoring Trends in Burn Severity program mapping production procedures and data products. Fire Ecology, 16, 16. https://doi.org/10.1186/s42408-020-00076-y
85 Kolden, C.A., Smith, A.M.S., and Abatzoglou, J.T. 2015. Limitations and utilisation of Monitoring Trends in Burn Severity products for assessing wildfire severity in the USA. International Journal of Wildland Fire, 24, 1023-1028. https://doi.org/10.1071/WF15082

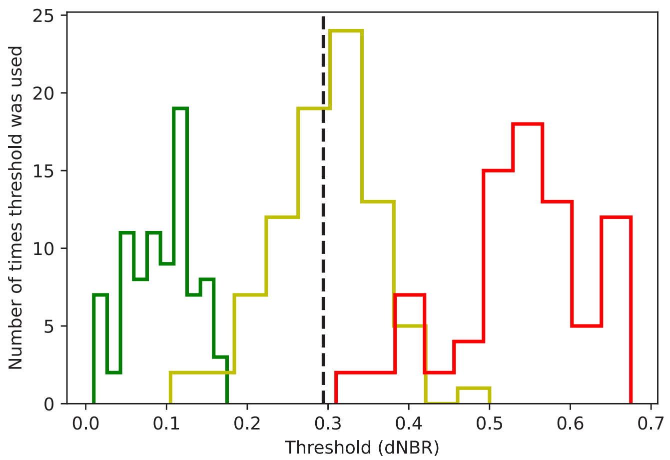


Figure 4-3. dNBR thresholds for "low", "moderate" and "high" MTBS classifications for fires within Northern Sierra Nevada pyrome.

For the purposes of the parametric insurance contract, we use the mean dNBR threshold (dNBR = 0.294) as the objective differentiator between low-severity and high-severity burn area. A listing of the largest 10 fires in our analytical dataset is provided in Appendix B.

- We also expect that the satellite method should detect these changes in burn severity, since MTBS unburned-low and low-severity classifications have a negligible amount of crown fire (personal communication, Seth Bogle, MTBS, 2020), and correlate moderately well to other ecological severity metrics and field validation (Picotte et al., 2020[86]). Therefore, any crown fire should be concentrated in MTBS moderate and high-severity classifications.

Ecological Forestry Treatment Insurance Pricing Benefits Estimation

Ecological forestry treatments are prescribed in our model by reducing the total burned area of historical fires by 40%. In the case of the severity of burned area product, the high-severity area of historical fires is reduced by 75%; the adjusted low-severity area is then calculated as the difference between the (adjusted) total burned area and the high-severity burned area.

These adjustments to burned area may seem quite large, but previous wildfire modeling studies support these choices. These reductions in burned area (40%) and high-severity burned area (75%) of historic fires have been modeled for Southern California after ecological forestry treatment. Specifically, for five fire events between 2013 and 2014 near San Francisco, high-severity burned areas defined as "areas within which modeled flame lengths exceeded 8 feet" reduced by an average of 75% (Buckley et al., 2014[87]).

Fire modeling undertaken for the French Meadows Project also suggests that high-severity burned area as measured by similar metrics (crown fire activity, crown fire fraction, flame length exceeding 4ft and 8ft) should decrease by 75% to 95% after ecological forest management (Smith, 2018[88]). Likewise, for the 2013 American Fire, extreme (>90%) basal area mortality reduced from 26% of land area in regions without ecological management to 11% in regions with ecological management, representing a 58% decrease in high-severity burn by this metric (Tubbesing et al., 2015[89]).

86 Picotte, J.J., Bhattarai, K., Howard, D., Lecker, J., Epting, J., Quayle, B., Benson, N, and Nelson, K. 2020. Changes to the Monitoring Trends in Burn Severity program mapping production procedures and data products. Fire Ecology, 16, 16. https://doi.org/10.1186/s42408-020-00076-y
87 Buckley, M., Beck, N., Bowden, P., Miller, M., Hill, B., Luce, C., Elliot, W., Enstice, N., Wilson, K., Winford, E., and Smith, S.L. 2014. Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense. Sacramento, California, Sierra Nevada Conservancy.
88 Smith, E. 2018. Tahoe National Forest, American River Ranger District French Meadows Project. Fire & Fuels Specialist Report. Sacramento, California, The Nature Conservancy.
89 Tubbesing, C.L., Fry, D.L., Roller, G.B., Collins, B.M., Fedorova, V.A., Stephens, S.L., and Battles, J.J. 2019. Strategically placed landscape fuel treatments decrease fire severity and promote recovery in the northern Sierra Nevada. Forest Ecology and Management, Vol. 436, 45-55. https://doi.org/10.1016/j.foreco.2019.01.010

Analytical Model Adjustments due to Climate Change Impacts

California's climate has been warming and drying over the last 40 years (Williams et al., 2019[90]) and the historical annual average wildfire burned area has increased. Based on analysis of the frequency and severity patterns of fires during the historical period used in this study, the increase in historical annual average burned area has occurred because the average burned area per fire has increased, while the number of fires per year and proportion of high burn severity has remained relatively constant.

Therefore, using historical estimates of burned area for fires may under-estimate the current risk of burned areas from wildfire. Change-point detection (i.e., PELT, Binary Segmentation, Window-based and Dynamic Programming Search methods) indicates a change-point between 2011 and 2012, when the average fire size increased by a factor of 3.03. For a simple adjustment for climate warming and drying, we increase the historical burned area for 1984–2011 by a factor of 3.03, resulting in a fire event series between 1984–2018 that is more representative of a warmer and drier modern California climate.

4.2 Insurance Quantification of Ecological Forestry Benefits

Per-burned-area Valuation

While traditional insurance uses the value of assets as the basis for settlement of claims (e.g., the cost to repair a damaged building), a parametric insurance solution needs an assumption of lost value of the insurable interest in order to construct an appropriate index structure which equates the measured hazard parameter (e.g., number of acres burned in a wildfire) to the impact that has on the insured party (e.g., lost value of timber, higher costs of operating due to debris clearance). In the simplest case, a parametric solution may pay out a single sum in the event of a fire, no matter the size of the fire. However, given that larger fires are generally more damaging (e.g., with larger fires there is more timber lost and more debris to clear), it is usual that the insured would need larger pay-outs from larger fires. A simple method to account for larger fires requiring larger pay-outs is to scale the pay-out linearly for the size of the fire (i.e., assign a monetary value to a unit of burned area).

It is important to note that in a parametric insurance structure, the value assigned to, for example, a burned acre of forest, has a direct and fully linear effect on the risk profile of the structure. Often, the insured party will provide significant input to the value assigned to the parametric index and, put simply, if one insured party demonstrates that its insurable interest in 1,000 acres of forest means that it needs double the pay-out for the burning of that 1,000 acres, relative to another party with insurable interest, the pure risk (AAL) will simply double.

Estimates of historical annual event loss have been computed from the historical dataset with realistic valuations per burned area. The valuations depend on use case (e.g., Table 4-3). The "average" burned area, without severity classification, is valued between $300 and $5,000/acre, while low-severity burned areas are valued between $100 and $2,000/acre, and high-severity burned areas are valued between $200 and $8,000/acre.

We provide here a brief justification for adopting these values, though it is difficult to generalize regarding the loss of an acre of western US forest. Fire suppression costs alone are valued at approximately $1,000 to $2,000/acre depending on burn severity and terrain.

For the King Fire in 2014, the proposed valuations result in $500–$575 million "losses" given the burned area of 99,000 acres. The El Dorado County Court ordered a $60 million fine to the arsonist that started the King Fire, covering restitution to victims[91]. Presumably, this fine is a reflection of indemnity losses for 12 residences and 100 other structures that were destroyed by the fire, which would equate to a mean loss of $535,000 per structure. It is possible that unaccounted fire suppression costs, ecological costs, business interruption costs, and longer-term water management costs exceed this $60 million "indemnity" value by an order of magnitude. Similar loss values have been estimated for the 2013 Rim Fire ($127 million, 257,000 acres) and 2002 Hayman Fire ($150 million, 138,000 acres) that do not include wider economic losses (Buckley et al., 2014[92]). Therefore, $500–$575 million of losses does not seem unreasonable for the King Fire.

91 https://www.reuters.com/article/us-california-fire-guilty/california-wildfire-selfie-arsonist-gets-20-years-60-million-fine-idUSKCN0X600X
92 Buckley, M., Beck, N., Bowden, P., Miller, M., Hill, B., Luce, C., Elliot, W., Enstice, N., Wilson, K., Winford, E., and Smith, S.L. 2014. Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense. Sacramento, California, Sierra Nevada Conservancy.

Comparative Historical Loss Estimation

Historical event losses were calculated using four alternative levels of fire-suppression impact of ecological forestry: none, reduced burned area only, reduced severity only, and reduced area and reduced severity. While the severity of a fire and total burned area are probably positively correlated, we include this type of ecological forestry impact to isolate the effect of reducing high-severity burned area on losses.

The historical losses based on each of the four different levels of ecological forestry impact were calculated using both of the parametric insurance approaches described above – i.e., burned area only and severity of burned area. We do not include "severity only" insurance because current insurance practices only account for total burned area. As such, the most feasible new insurance solution accounts for both total burned area and incorporates severity as a weighting. In total, the historical event losses were calculated for eight scenarios of ecological-forestry impact and insurance coverage types. We refer to Scenario 1 as the Baseline (no ecological forestry impact and insurance that only recognizes total burned area), and Scenario 8 as "Full ecological forestry benefit", the other end of a spectrum, where ecological-forestry impacts on both total burned area and severity of burn, and insurance recognizes high-severity burned area.

Premium Calculation for Parametric Wildfire Insurance

Fire frequency is modeled by assuming a uniform fire frequency-density across the Northern Sierra Nevada pyrome. The fire frequency-density was set to 1.26×10−4 fires/year/km^2, because 156 wildfires were larger than 1,000 km^2 over the Northern Sierra Nevada pyrome (35,293 km^2) between 1984–2018. In the model, the Northern Sierra Nevada pyrome is constructed as a 35,293 km^2 ellipse with an ellipticity of 2.6. Within this ellipse, fires are initiated at uniformly distributed random points each year. It is assumed that there is no change in the annual fire frequency with ecological forestry because fires are caused by humans (~84%) or triggered by lightning (~16%) (Balch et al., 2017)[93] and neither ignition process is necessarily mitigated by the *ex ante* fire management strategies proposed here.

After the fire initiation points are modeled, fire areas are modeled as circles with the uniformly distributed points assigned as the center of each fire. The area of each fire is chosen at random from a Generalized Pareto distribution, which was derived from the area of 155 fires in the historical database. Within the historical database, the area of each fire prior to 2012 is multiplied by a factor of 3.03 to account for climate change (e.g., Table 4-1). The proportion of high-severity area of modeled fires is fixed at 47.5%, the proportion in the historical database for the Northern Sierra Nevada pyrome.

The area that benefits from the effect of ecological forestry management is modeled as a circle within the Northern Sierra Nevada pyrome. If a modeled fire initiates within the area benefitting from ecological forestry, then the area of the fire is drawn from a different distribution. Those fire areas are chosen at random from a Generalized Pareto distribution that was derived from the 155 historical fires after the application of ecological forestry burn-area reductions. The proportion of high severity area of these modeled fires was fixed to 29.7%, the same proportion as in the historical database after accounting for ecological forestry measures.

The area of forest covered by the wildfire resilience parametric insurance product is modeled as circular to reduce unnecessary analytical complexity, noting that the actual shape of a parametric insurance coverage area is not required to be a circle. The modeled burned area per event is calculated as the intersection between the insured area and the modeled area of a fire event. Insurance structures are then applied to each modeled burned area per event with event deductibles, event limits, and aggregate limits.

Premiums are primarily designed to cover the cost of insurance pay-outs and ensure long-term profit for an insurer. Thus, insurance premiums are primarily calculated according to simulated insurance pay-outs. Simulated insurance pay-outs are calculated after the deductibles and limits (event or annual aggregate, for example) are taken into account. For this study, we produced a distribution of pay-outs over 500,000 simulated years.

Baseline premiums are then calculated from the pay-outs over 500,000 simulation years. The average annual pay-out is the expected pay-out of the insurer over a long time (i.e., the expectation value), which is the minimum amount that an insurance policy should cost if actuarially priced. However, there are other considerations for an insurer besides the annual average loss. For simplicity, we assume a loading factor of 20% of the standard deviation of the average annual pay-out to cover the operational and capital costs to the insurer. The sum of the annual average pay-out and the loading is referred to as the net premium.

While the insurer receives the net premium, the insured pays the gross premium. The gross premium is necessarily larger than the net premium, as it also covers the costs of tax, brokerage, data settlement and other costs that are borne by the insured. Together, these extra costs are typically 10% of the net premium (expressed as extra costs = 0.1). Thus, we divided the net premium by 0.9 (corresponding to 1 – extra costs) to produce an estimate of gross premium that is paid by the insured. In short, the gross premium (GP) is calculated as follows:

GP = {expected annual average pay-out + (loading factor × standard deviation of annual average pay-out)} / (1 – extra costs)

As a final output of the modeling, we compare the gross premiums for different ecological forestry impacts and insurance coverage types against the baseline case to evaluate the premium reduction benefits of ecological forestry across the range of use cases tested.

Results

Average historical event losses decrease by at least 40% for all ecological forestry scenarios that reduce the total burned area, regardless of insurance type (Table 4-1, Scenarios 3, 4, 6, 7, and 8). When adjusting historical burned areas for ecological forestry that reduced total burned area by 40%, historical average event losses with insurance coverage that only recognizes total burned area (Scenarios 3 and 7) decreases correspondingly by 40%. With other scenarios that account for burn severity (Scenarios 4, 6, and 8), historical average event losses decrease by 40% to 62%. As expected, reducing total burned area, via ecological forestry, reduces historical average event losses regardless of insurance type.

Historical event losses were slightly smaller when insurance coverage type accounts for high-severity burned area but the ecological forestry is assumed to have not reduced high-severity burned area (cf. Scenario 1 with Scenario 2 and cf. Scenario 3 with Scenario 4). Historical average event losses decrease under these scenarios because, on average, there is less high-severity burned area (48% of total) than low-severity burned area (52% of total). Thus, when weighting the losses by high-severity burned area, historical average event losses decrease. When insurance accounts for high-severity burned area, but ecological forestry only reduces total burned area, then historical average event losses decrease by 3% to 4%. This result (lower costs when including burn severity) does not necessarily hold if the historical fire burn severity skews towards high-severity burned area (i.e., if >50% of historical burned area is high-severity).

Ecological forestry scenarios that only reduce burn severity, without reducing total burned area, were included for controlled comparison between reducing total burned area and reducing high-severity burned area (Scenarios 5 and 6). When insurance cover does not recognize burn severity, there is no change from baseline historical average losses. However, when insurance does recognize burn severity, the historical average losses decrease by 46% from baseline. As such, reducing high-severity burned area appears to be a solution that could be as competitive as reducing total burned area alone (if the sole aim were to reduce insured losses). This result may not hold for less aggressive reductions of high-severity burn area (i.e., <75%), more aggressive reductions in total burned area (i.e., >40%), or lower cost differentials between high-severity burned area ($8,000/acre) and low-severity burned area ($2,000/acre). Nonetheless, this result is surprising and important, and shows that reducing high-severity burned area alone can reduce losses by as much as reducing total burned area.

Historical average event losses are reduced by the largest amounts when ecological forestry reduces total burned area and high-severity burned area, and insurance recognizes the reduction in high-severity burned area (i.e., Scenario 8). With insurance fully accounting for the benefits of ecological forestry, historical average event losses reduced by 62% compared to baseline losses (Table 4-2). For a sensitivity analysis, models were re-parameterized by halving the ecological forestry success. This parametrization corresponds to 20% reduction in total burned area and 37.5% reduction in high-severity burned area. With the parametric insurance scenario (Scenario 8), which accounts for the full benefit of ecological forestry, this halving of ecological forestry success approximately halved the reduction in historical average event losses (from 62% to 32%).

93 Balcha, J.K., Bradley, B.A., Abatzogloue, J.T., Nagya, R.C., Fuscod, E.J., and Mahooda, A.L. 2017. Human-started wildfires expand the fire niche across the United States. Proceedings of the National Academy of Sciences, 114 (11) 2946-2951. https://doi.org/10.1073/pnas.1617394114

Table 4-1. Historical annual event losses for each ecological forestry impact scenario, with climate adjustment between 1984–2011 (multiplying fire event size by 3.03). Ecological forestry scenarios include "none" (no change), ecological forestry that reduces total burned area, ecological forestry that reduces burn severity only, and ecological forestry that reduces both burned area and burn severity. The change from baseline is the reduction in parametric insurance coverage provided by ecological forestry with the parameterizations of this model.

Scenario	Ecological forestry benefit	Insurance coverage type	Historical average event loss	Change from baseline
1 (Baseline)	None	Total burned area	$144m	n/a
2	None	Total burned area & severity	$141m	- 2%
3	Reduced total area only	Total burned area	$87m	- 40%
4	Reduced total area only	Total burned area & severity	$85m	- 41%
5	Reduced severity only	Total burned area	$144m	0%
6	Reduced severity only	Total burned area & severity	$79m	- 45%
7	Reduced area & reduced severity	Total burned area	$87m	- 40%
8 (Full ecological forestry benefit)	Reduced area & reduced severity	Total burned area & severity	$55m	- 62%

The reason for including the sensitivity analysis is twofold:

- First, our estimates of ecological forestry benefits may fundamentally over-estimate the reductions of total burned area and high-severity burned area. We have mitigated this issue by assuming a relatively low reduction in high-severity burned area (75%) that is based on modeling around southern California (Buckley et al., 2014[94]) and agrees with the reduction in crown fire activity modeled across the French Meadows region (Smith, 2018[95]). For context, we could have chosen a much higher reduction in high-severity burned area (95%) that is based on the reduction in modeled flame lengths greater than eight feet in the French Meadows region.

- Second, there may be errors associated with severity classification and thresholds by the proposed satellite method. More broadly, this second error is a problem with the implementation of the insurance product but not the fundamental ecological forestry concepts. For example, a "high-severity burned area" (as classified by the satellite-based insurance solution) may not be re-classified to a correct "low-severity burned area" because the dNBR / RdNBR threshold is too low or satellites may not pick up severely-burned regions that are covered by forest canopy. To move forward, and because capturing burn severity in an insurance product is a new concept, we assume that the satellite-based insurance solution will appropriately capture changes between high-severity and low-severity classes.

Although parametric insurance coverages relevant to the entire Northern Sierra Nevada pyrome are not realistic, for illustrative purposes we have assumed full coverage and some representative deductibles and limits to demonstrate the gross premium reduction which would arise from the reductions in expected losses due to wholesale ecological forestry treatment across the pyrome.

Table 4-2. Premiums to insure the total Northern Sierra Nevada area (35,000 km^2, 8.6 million acres) given complete ecological forestry.

Insurance "purpose"	Scenario	Deductible	Limit	Gross premium	Rate online	Change from baseline	Pay-out recurrence rate (years)
Disaster	Baseline	$300m	$500m	$294m	59%	n/a	1.5
	Full benefit of ecological forestry	$300m	$500m	$84m	17%	- 71%	3.5
Catastrophe	Baseline	$500m	$500m	$214m	43%	n/a	2.1
	Full benefit of ecological forestry	$500m	$500m	$38m	8%	- 82%	9.4

94 Buckley, M., Beck, N., Bowden, P., Miller, M., Hill, B., Luce, C., Elliot, W., Enstice, N., Wilson, K., Winford, E., and Smith, S.L. 2014. Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense. Sacramento, California, Sierra Nevada Conservancy.
95 Smith, E. 2018. Tahoe National Forest, American River Ranger District French Meadows Project. Fire & Fuels Specialist Report. Sacramento, California, The Nature Conservancy.

4.3 Scenarios for Parametric Coverage in Eastern Placer County

To bring our analysis to real-world situations, we have compared the premium cost across 20 examples of parametric insurance coverages, based on variations around three overall use-cases:

i) For PCWA, a use case which is designed to cover major log and heavy debris removal from PCWA facilities quickly after a wildfire;

ii) For PCWA, a second use case which is designed to cover the cost of sediment removal / dredging from PCWA facilities and/or the cost of mitigating sediment erosion through immediate post-fire aerial mulching on US Forest Service lands;

iii) For a hypothetical timber stakeholder, a use case covering the lost sale value of timber lost in a wildfire.

The first two parametric insurance use cases, for PCWA, are based on actual and potential costs encountered by the PCWA in the aftermath of the 2014 King Fire. The 2014 King Fire burned over 97,000 acres within the watershed of the Placer County Water Agency. The acres burned were mostly El Dorado National Forest lands of the USFS. While the King Fire did not burn or damage directly PCWA assets or facilities, there were several significant potential and actual costs faced by PCWA after the 2014 King Fire.

First, there were potential and actual costs associated with the removal of heavy debris, including burned logs and other debris which ended up in the waters of the PCWA watershed and then were carried into PCWA reservoirs, hydro-power bays or other PCWA hydro-power facilities. These heavy debris could interfere with PCWA hydro-power generation operations and facility safety. PCWA spent about $1 million in the year following the King Fire in 2014 to remove debris from one of its hydro-power plants after bays.[96]

Second, there were potential and actual costs associated with sediment collecting in PCWA facilities, resulting from the erosion of soil in areas burned by the fire, with the erosion subsequently triggered by rainfall. Sediment interferes with hydro-power generation operations and can be highly destructive and one of the most dangerous post-fire hazards.[97] The potential of damage by debris flow is greatest in the months to several years after a fire event has occurred. PCWA spent at least an additional $6 million to remove sediment from PCWA facilities following a heavy rainfall in early 2017.[98]

Another potential cost related to post-fire sediment flows is the cost associated with trying to prevent erosion of slopes in the watershed. The USFS undertook an analysis of potential erosion and projected sediment flows impacting PCWA facilities, in the immediate aftermath of the 2014 King Fire, which determined that undertaking aerial mulching of 1,730 acres of forest service lands would reduce sediment flows from the treated acres by 77%, in turn eliminating 34,365 tons of sediment. Aerial mulching involves dropping by helicopter mulch on burned slopes within the watershed in order to reduce erosions and sediment flows. The USFS offered to undertake aerial mulching of the 1,730 acres for $1.3 million.[99] While PCWA declined to incur that expense, the cost of post-fire sediment erosion mitigation is another category of potential cost associated with wildfire which a water and power utility can be expected to face.[100]

Based on the potential and actual costs incurred by PCWA after the King Fire, the first two parametric insurance use cases were developed to address the potential post-wildfire costs to a water and power utility associated with (i) heavy debris removal and (ii) sediment removal and sediment prevention through erosion-control practices like aerial mulching.

In each of the first two cases, we have constructed two alternative coverage areas. The first is relatively small (20,000 acres), including the French Meadows and Hell Hole reservoirs. The second is larger (41,000 acres), representing the French Meadows reservoir and the Middle Fork American River watershed around and upstream of the reservoir. Both the first and second areas are assumed to fully encompass the treated area of the French Meadows project. However, the second area is coincident with the "area of influence" of the ecologically treated area of the French Meadows project (i.e., the second area is the same area as the buffer zone). For the third case (case (iii), the timber stakeholder), an even larger area is covered (90,000 acres). This third area includes the full area of influence if the entire French Meadows project area were to be treated with ecological forestry (28,000 acres).

For each of the five use case / size scenarios, we have tested the risk analytics and coverage pricing for two alternatives, one with ecological forestry (the actual current treated area of the French Meadows project for all but case (iii), which assumes the entire French Meadows project area is treated) and the other without.

Finally, we tested these 10 cases under both the Burned Area and Severity of Burned Area parametric structures. Table 4-3 shows the key characteristics of each case, the associated parameters used for modeling, and the results.

Sediment removal operation at PCWA's Ralston Afterbay facility. © PCWA

96 PCWA Memorandum Re: Ralston After Bay Debris Management Project, Contract No 2015-15, Contract Change Order No. One, 6/23/2016. Listing project expenses to date as $930,969.56 to remove debris from PCWA Ralston After Bay.

97 https://ca.water.usgs.gov/wildfires/wildfires-debris-flow.html

98 PCWA Memorandum Re: 2017 Middle Fork American River Project Sediment Removal Project- Budget Amendment,4/6/2017. Approving a budget amendment to allocate $5 million to sediment dredging/removal. "This winter sediment accumulation has been far greater than normal and now impedes the reservoirs reducing the capability of the Middle Fork Project to divert water, manage its flow, and produce power. With approval of project funding, design and permitting will proceed immediately. Construction is scheduled for fall 2017. The estimated cost is $5,000,000.";

See also PCWA Memorandum Re: Santos Excavating Inc. 2018 Sediment Dredging Services Agreement, 12/18/2017, increasing sediment removal project budget from $5 million to $6 million. "In early 2017, the Middle Fork Project experienced record historic storms that eroded large areas of recently burned terrain within the watershed resulting in the deposition of large volumes of sediment in project rivers and reservoirs. The winter sediment accumulation has been far greater than normal and now impedes the ability to operate the Low-level Outlet at Ralston Afterbay Dam. Currently we are out of compliance with dam safety requirements set forth by the California Department of Water Resources, Division of Safety of Dams. The Low-level Outlet slide gate is fully buried and is currently inoperable. Up to 5,000 cubic yards of material is estimated for removal in order to re-establish normal operability." ..."In 2017, use of $5,000,000 from the MFPA Capital Reserve Account was approved by a Budget Amendment...for sediment removal efforts. An additional $1,000,000 has been approved for 2018."

99 See analysis of aerial mulching costs and benefits provided by USFS Burned Area Emergency Management team to PCWA staff after the 2014 King Fire. Provided by PCWA staff to the authors.

100 After the King Fire, the Sacramento Municipal Utility District whose watershed was also impacted by the fire, appropriated $400,000 to pay the USFS to undertake aerial mulching of 300 acres of burned US Forest lands in order to reduce erosion and consequent sediment impacts on SMUD hydro-power facilities. The USFS analysis determined that aerial mulching of critical slopes would reduce sediment by 65% to 70% and prevent 6,200 tons of sediment from flowing into SMUD's Slab Creek Reservoir. SMUD determined that the cost of removing 6,200 tons of sediment from the reservoir would be between $230,000 and "well over" $1 million, with the cost likely to be toward the higher end of the range. See Collection Agreement Between the Sacramento Municipal Water District and the USDA Forest Service, Eldorado National Forest, dated 11/12/14, FS Agreement 15-CO-11500300-000. See also SMUD Direct Procurement Justification, King Fire Restoration Erosion Control.

Table 4-3. Summary characteristics of all 20 use case / covered area / parametric insurance coverage type variations tested, and annual premium estimates for each, along with savings (relative to the "Burned Area, no ecological forestry" case in each use case / covered area pair).

Client	Defined Area	Area insured (acres)	Use-case	Tick (average pay-out per acre burned, $)	Event Attach (acres)	Event Exhaust (acres)	Event deductible ($)	Event Limit ($)	Scenario	Area with ecological forestry (acres)	Area benefitting from ecological forestry fire suppression (acres)	Insurance Type	Annual Premium ($)	Insurance savings (%)
PCWA	A tightly defined region around French Meadows and Hell Hole reservoirs	20,000	(i) Debris removal	300	100	8,433	30,000	2,500,000	(i)(a)	None	None	Burned Area, no ecological forestry	144,000	-
												Burned Severity, no ecological forestry	135,000	6%
									(i)(b)	12,183	40,610	Burned Area with ecological forestry	115,000	20%
												Burned Severity with ecological forestry	105,000	27%
			(ii) Slope stability treatment	1,000	100	5,100	100,000	5,000,000	(ii)(a)	None	None	Burned Area, no ecological forestry	330,000	-
												Burned Severity, no ecological forestry	295,000	11%
									(ii)(b)	12,183	40,610	Burned Area with ecological forestry	290,000	12%
												Burned Severity with ecological forestry	240,000	27%
	The hydrological watershed above the French Meadows reservoir that benefits from all ecological forestry across the project area	40,610	(i) Debris removal	148	100	17,021	14,775	2,500,000	(i)(c)	None	None	Burned Area, no ecological forestry	155,000	-
												Burned Severity, no ecological forestry	147,000	5%
									(i)(d)	12,183	40,610	Burned Area with ecological forestry	130,000	16%
												Burned Severity with ecological forestry	120,000	23%
			(ii) Slope stability treatment	492	100	10,253	49,249	5,000,000	(ii)(c)	None	None	Burned Area, no ecological forestry	365,000	-
												Burned Severity, no ecological forestry	334,000	8%
									(ii)(d)	12,183	40,610	Burned Area with ecological forestry	340,000	7%
												Burned Severity with ecological forestry	293,000	20%
Hypothetical timber stakeholder	A large region of importance to a hypothetical timber stakeholder	90,000	(iii) Lost timber assets	1,000	5,000	17,500	5,000,000	12,500,000	(iii)(a)	None	None	Burned Area, no ecological forestry	1,000,000	-
												Burned Severity, no ecological forestry	975,000	3%
									(iii)(b)	28,000	93,333	Burned Area with ecological forestry	780,000	22%
												Burned Severity with ecological forestry	640,000	36%

The main results are summarized as follows:

- The premiums tend to be similar for normal burned area and severity of burned area parametric insurance forms when there is no ecological forestry.
- The premium for both coverage types decreases significantly with ecological forestry.
- The premiums tend to decrease more with the severity of burned area parametric insurance type than with normal burned area parametric design. This is because of the greater impact of ecological forestry on decreasing high-severity burned area.
- The premiums with ecological forestry are generally 10% to 40% lower than premiums without ecological forestry.
- The premiums can decrease by different amounts because of how the insurance structure works (limits etc.), and whether the particular coverage fully takes advantage of the change in loss profile induced by ecological forestry. These premium savings should therefore only be considered as broadly representative of potential real-world use cases.

Ecologically thinned forest. © David Edelson/TNC

Section 5: Analysis of Premium Savings and Ecological Forestry Treatment Costs

This section of the paper will compare insurance premium savings associated with ecological forestry to the cost of ecological forestry. It will discuss how the insurance premium savings quantified in earlier sections of the paper might contribute to funding or financing ecological forestry projects, and how those premium savings might be captured to assist in funding or financing ecological forestry projects. This section will also consider, based on the insurance benefits discussed in prior sections, how ecological forestry may be critical to enabling private insurers to continue to provide needed insurance to homes and business in areas at risk of wildfire.

5.1 Need for More Funding for Ecological Forestry

Forests cover one-third of California — roughly 33 million of California's approximately 100 million acres.

There is a large backlog of forest acreage in need of ecological forest treatment in California. According to a report issued by the California Legislative Analyst's Office (LAO) in 2018[101], "ongoing state and federal funding for proactive forest management in California has averaged around $100 million annually in recent years, treating an estimated 280,000 acres per year." The LAO Report also found:

101 California Legislative Analyst's Office. 2018. Improving California's Forest and Watershed Management. https://lao.ca.gov/Publications/Report/3798

The draft Forest Carbon Plan states that 20 million acres of forestland in California face high wildfire threat and may benefit from fuels reduction treatment. According to the plan, Cal Fire estimates that to address identified forest health and resiliency needs on non-federal lands, the rate of treatment would need to be increased from the recent average of 17,500 acres per year to approximately 500,000 acres per year...

Based on its ecological restoration implementation plan, USFS estimates that 9 million acres of national forest system lands in California would benefit from treatment. The draft Forest Carbon Plan sets a 2020 goal of increasing the pace of treatments on USFS lands from the current average of 250,000 acres to 500,000 acres annually, and on BLM lands from 9,000 acres to between 10,000 and 15,000 acres annually.

The State of California and the US Forest Service entered into an agreement in August 2020, which includes a commitment by the federal government to match California's goal of reducing wildfire risks on 500,000 acres of forest land per year ("The Agreement for Shared Stewardship of California's Forest and Rangelands"[102]), for a total of one million acres of forest to be treated a year. Although the State of California has appropriated $200 million a year for five years from 2019 to 2024 for forest management, and in April 2021 appropriated $536 million to address wildfire resilience of which $477 million is for forest treatment[103], this amount still falls short of what is needed to treat 500,000 acres per year, which is the State of California's goal. Across the United States there is substantial forest lands which require treatment. According to the Forest Service, their models suggest that targeted treatments are needed on 57 million acres of federal, state, tribal, and private lands to significantly reduce exposure in the highest risk areas.[104] A minimum investment of approximately $6 billion (an estimated $2.7 billion for national forests and $3 billion for other federal, tribal, state, and private land ownerships, and for community investments) per year over the next 10 years is needed for the highest priority work to reduce wildfire risks, with substantial additional resources needed for community and infrastructure investments.[105]

Additional public and private dollars are needed for ecological forest treatment of California's and the nation's public and private forest lands. Next, we will analyze how insurance premium savings associated with accounting for ecological forestry might contribute to the funding or financing of more ecological forestry treatment.

5.2 Per Acre Cost of Ecological Forestry

In order to determine how and to what extent premium savings associated with ecological forestry might contribute to funding or financing ecological forestry treatments, first we need to determine what the per acre cost is of ecological forest treatments, and then compare that cost with insurance premium savings over time.

Prescribed burn in Independence Lake area, Tahoe National Forest. © TNC

102 https://www.gov.ca.gov/wp-content/uploads/2020/08/8.12.20-CA-Shared-Stewardship-MOU.pdf
103 "Gavin Newsom signs bill to rush spending on California wildfire prevention as drought sets in". Sacramento Bee, April 13, 2021. https://www.sacbee.com/news/politics-government/capitol-alert/article250622984.html
104 House Appropriations Subcommittee on Interior, Environment, and Related Agencies Hearing on U.S. Forest Service FY2022 Budget Request, response by USDA Chief Victoria Christiansen, April 15, 2021.
105 See Clavet, C., Topik, C., Harrell, M., Holmes, P., Healy, R., and Wear, D. Forthcoming. Wildfire Resilience Funding: Building Blocks for a Paradigm Shift. Arlington, Virginia, The Nature Conservancy.

Ecological forestry practices include a number of individual practices, including but not limited to hand thinning, mechanical thinning, mastication, prescribed burning, chipping, and pile burning. Costs per acre vary significantly by forest stand, based on accessibility of areas to be treated, availability of qualified contractors, topography of area treated, disposal costs, and proximity to and demand from off-takers of bio-mass (Gartner et al., 2018 [106]).

Ecological forestry treatment costs can be divided into two general categories for purposes of this analysis – thinning and prescribed fire. While forest treatment typically involves both thinning and burning, the costs for each may vary widely across different geographies (Hartsough et al., 2008[107]; North et al., 2012[108]). Costs for the French Meadows project are, at the time of writing, averaging $1,166 for mechanical thinning and an estimated $1,039 per acre of burning.[109]

The USFS recently estimated that the average cost of forest treatment for national forest lands is $1,000 per acre (Clavet et al.[110]). For purposes of this insurance study, we adopt this estimate and apply it to both prescribed burning and thinning.

It is important to note that in order to reduce wildfire risk, ecological forest treatments have to occur over substantial amounts of acreage. The French Meadows Project, for example, involves 7,000 acres of thinning and 6,000 acres of prescribed burns within a 28,000-acre project area.

It is well documented that there are many beneficiaries of ecological forestry and a variety of economic benefits (Buckley et al., 2014[111]). This project and paper, however, focuses on quantifying the insurance-related economic benefits of accounting for ecological forestry in insurance modeling and structuring.

Next, we will analyze and compare the insurance premium savings from ecological forestry, based on the results from the proceeding sections, with the costs of ecological forestry.

106 Gartner, T., Connaker, A., and Woolworth, N. 2018. Investors Think They Can Make Money Reducing Wildfire Risk. A Forest Restoration Project in Yuba, CA Puts this Idea into Practice. Washington, DC, World Resources Institute. https://www.wri.org/insights/investors-think-they-can-make-money-reducing-wildfire-risk-forest-restoration-project-yuba
107 Hartsough, B., Abrams, S., Barbour, R., Drews, E., Mciver, J., Moghaddas, J., Schwilk, D., and Stephens, S. (2008). The economics of alternative fuel reduction treatments in western United States dry forests: Financial and policy implications from the National Fire and Fire Surrogate Study. Forest Policy and Economics, 344-354. https://doi.org/10.1016/j.forpol.2008.02.001
108 North, M.P., Collins, B.M., and Stephens, S.L. 2012. Using fire to increase the scale, benefits and future maintenance of fuels treatments. Journal of Forestry, 110(7), 492-401. https://doi.org/10.5849/JOF.12-021
109 Per acre costs for French Meadows Project from "French Meadows Forest Restoration Project: First Year Operations Summary Report", April 31, 2020, Placer County, indicate that actual costs for the French Meadows Project are slightly higher than the USFS estimate. However, the USFS estimate is more general in that it is an estimate of average costs which accounts for the variance in specific costs for a number of projects some of which may be quite different from French Meadows.

A detailed cost break-down for the French Meadows Project based on the "First Year Operations Summary Report, April 30, 2020 is given below. Note that several major cost categories (e.g., "Rec site thinning" and "Road improvements") are specific to the project and may not be needed more generally. Also, prescribed burning was not part of the treatment program in the first year due to adverse meteorological conditions but will be used in later years of the project. Per acre prescribed burn implemntation costs for the French Meadoes Project are budgeted at $1,039 per acre according to "Sierra Nevada Conservancy Grant Agreement #1130 French Meadows Prescribed Fire Project, September 12, 2019".

Project Cost Summary	Acres	Net cost ($/ acre)	Cost ($)	% of total
Mechanical Thinning	440	1166	513,040	20%
Mastication	300	1163	348,900	13%
Hand Thinning	225	1249	281,025	11%
Rec site thinning	100	3913	391,300	15%
Road improvements	-	-	530,707	20%
Project planning	-	-	546,176	21%
Total	-	-	2,611,148	100%

Source: "First year (2019) Operations Summary Report", Placer County, PCWA, TNC et al April 30, 2020.
110 Clavet, C., Topik, C., Harrell, M., Holmes, P., Healy, R., and Wear, D. Forthcoming. Wildfire Resilience Funding: Building Blocks for a Paradigm Shift. Arlington, Virginia, The Nature Conservancy.
111 Buckley, M., Beck, N., Bowden, P., Miller, M., Hill, B., Luce, C., Elliot, W., Enstice, N., Wilson, K., Winford, E., and Smith, S.L. 2014. Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense. Sacramento, California, Sierra Nevada Conservancy.

5.3 Comparison of Premium Savings to Ecological Forestry Costs

This section will discuss the insurance savings associated with the different types of insurance referenced above, for which ecological forestry's wildfire risk reduction was accounted. The premium savings will be compared to the costs of ecological forestry.

A. Indemnity Insurance Savings Results for PCWA

PCWA has physical assets valued at over $1.7 billion associated with its water and energy supply operations. PCWA purchases indemnity insurance to insure those assets. However, as discussed above, most of those structures are not vulnerable to loss from wildfire because of the nature or materials used in constructing those structures. Structures include tunnels, reservoirs, canals, and other structures which are not vulnerable themselves to loss from wildfire.

Because the majority of assets are not vulnerable to wildfire, there is almost no risk reduction benefit for those structures associated with ecological forestry from an indemnity insurance perspective, and therefore no likely savings in indemnity property insurance premium.

As also discussed in Section 2.1, PCWA has a limited number of buildings (13) which are vulnerable to wildfire because of the nature of their construction or construction materials. For those limited number of buildings, ecological forestry was found to reduce expected losses by 44% on average and result in an associated reduction in premium where property insurance is written separately for those buildings and ecological forestry accounted for.

As there is a limited number of these buildings and limited value at risk, the absolute premium savings would be relatively small.

However, these results importantly demonstrate a potential indemnity property insurance savings generally for commercial property vulnerable to wildfire within or adjacent to areas undergoing ecological forestry treatment, including US Forest lands. For example, there is approximately $3.75 billion in commercial and industrial property at risk in and within a 5km area around the PCWA watershed, which would potentially benefit in a reduction in expected loss and a reduction in premium for indemnity property insurance covering wildfire risk, were ecological forestry to be undertaken across 30% of the PCWA watershed.

B. Wildfire Resilience Parametric Insurance Savings Results Compared to Ecological Forestry Costs

Next, we will compare to ecological forestry costs the amount of premium savings from the various examples of our three "use cases" for wildfire resilience parametric insurance (debris removal, slope stability / debris removal and lost timber assets).

An initial ecological forestry treatment is assumed to be effective for 15 years. Longer timeframes of up to 30 years' effectiveness would require a prescribed burn of 100% of the original treatment area at year 15 to extend the effectiveness of the treatment for another 15 years (Stephens et al., 2012[112]).

Scenarios 1a and 1b represent the use of a wildfire resilience insurance parametric product that accounts for burn severity. whose use case is to provide proceeds which could be used to pay for potential debris removal costs incurred by PCWA after a wildfire and which covers an area of 20,000 acres around the French Meadows reservoir. Scenario 1a provides the baseline with no ecological forestry. whereas scenario 1b uses ecological forestry to treat 12,183 acres.

Compared with using a parametric insurance product that does not account for burn severity, scenario 1a (with no ecological forestry) results in a $9,000 (6%) savings annually. If ecological forestry is included as in scenario 1b, then the relative savings increase to $39,000 (27%) annually.

In scenarios 2c and 2d, the area insured is 40,610 acres, covering the watershed around French Meadows. Relative to the burned area equivalent product, the savings in scenario 2c are $31,000 (8%) while for scenario 2d (including ecological forestry treatment of 12,183 acres) the savings are $72,000 (20%) annually.

112 Stephens, S.L., McIver, J.D., Boerner, R.E.J., Fettig, C.J., Fontaine, J.B., Hartsough, B.R., Kennedy, P.L., and Schwilk, D.W. 2012. Effects of forest fuel-reduction treatments in the United States. Bioscience, 62, 549-560. https://doi.org/10.1525/bio.2012.62.6.6

Table 5-1. Annual premium savings for selected wildfire resilience parametric insurance scenarios.

Scenario	Use case	Ecological forestry	Area insured (acres)	Annual premium ($)	Insurance savings compared to Burned Area with no ecological forestry ($)	Insurance savings compared to Burned Area with no ecological forestry (%)	Ecological forestry costs offset per year from insurance savings (%)
1a	Debris removal	No	20,000	135,000	9,000	6.3%	-
1b	Debris removal	Yes	20,000	105,000	39,000	27.1%	0.3%
2c	Slope stability/ debris removal	No	40,610	334,000	31,000	8.5%	
2d	Slope stability/ debris removal	Yes	40,610	293,000	72,000	19.7%	0.6%
3a	Lost timber assets	No	90,000	975,000	25,000	2.5%	
3b	Lost timber assets	Yes	90,000	640,000	360,000	36.0%	1.3%

Scenarios 3a and 3b cover the use case of insuring timber assets for a hypothetical timber company with the area insured covering 90,000 acres. The savings under 3a relative to the burned area parametric product are $25,000 (2.5%) whereas, including ecological forestry treatment of 28,000 acres, scenario 3b results in savings of $360,000 (36%).

Looking at just the scenarios that include ecological forestry (1b, 2b, and 3b), the percentage of ecological forestry costs that can be paid for using the annual insurance savings range from 0.3% in scenario 1b to 1.3% in scenario 3b, and increase with the area insured and area benefitting from ecological forestry. While the annual cost offset is modest in size, each ecological forestry treatment is assumed to be effective for 15 years and therefore the annual insurance savings rebate should apply across all 15 years as well. The annual cost offset is from only one user of the insurance – multiple users of the insurance in an area benefitting from ecological forest treatment will increase the total cost offset.

C. Comparison of Aggregate Residential Insurance Savings to Ecological Forest Treatment Costs

Ecological forestry can result in significant residential insurance premium savings. In our study, the aggregate residential insurance savings associated with ecological forestry undertaken across the PCWA watershed compares favorably with the associated cost of ecological forest treatment across the watershed.

As discussed in Section 3.2 above, if ecological forest treatment was undertaken on 30%, or 194,427 acres, of the entire PCWA watershed, the risk of wildfire losses for the 81,000 residential structures within a 5km area around the watershed is reduced, for an annual premium savings of $21 million. Assuming for purposes of analysis that these savings persist for the 15-year period during which ecological forest treatment remains effective, an aggregate premium savings of $315 million[113] is obtained, whereas the cost of forest treatment for 194,427 acres, assuming a per acre cost of treatment of $1,000, is $194.43 million.

113 This and all other monetary values summed over different time periods are not discounted. This is justified in the sense that the actual implementation of eco-forestry treatments will almost always occur over multiple years but the exact timing will be project specific. We are therefore unable to discount the sequence of treatment costs and prefer not to discount other elements (benefits) in isolation.

As the table below shows, the residential premium savings compares favorably to ecological forestry costs over time. The net savings increase with the duration of the program, ranging from $15.57 million for 10 years to $120.57 million over 15 years. The annualized treatment costs are less than the annual premium savings for all time periods, leading to an increasing benefit-cost ratio (1.08 - 1.62) as the effective duration of the treatment is extended. In other words, the benefits accrued increase as the ecological forestry program approaches the full duration of the initial treatment.

In the next section, we will discuss how insurance premium savings might be "captured" and applied to fund or finance ecological forest treatment.

Comparison of Aggregate Residential Premium Savings to Ecological Forestry Costs

Duration (years)	Ecological forest treatment costs ($M)	Total Premium Savings ($M)	Net Savings ($M)	Benefit-Cost Ratio
10	194.43	210	15.57	1.08
15	194.43	315	120.57	1.62

5.4 Use of Premium Savings for Forest Treatment Funding

The premium savings from a wildfire resilience insurance product which accounts for both the severity of burned area and the benefits of ecological forestry may be substantial, particularly when the area insured includes multiple insured parties that benefit over 10 years or more.

This section will explore how bond financing might be coupled with wildfire resilience insurance savings, where the insurance premium savings are used to contribute to the debt service on bonds issued to fund or finance ecological forestry, which in turn is reducing risk and reducing the price of wildfire resilience insurance. The issuer of the bonds will vary across different use cases or scenarios studied in this paper.

For purposes of this analysis, PCWA is assumed to be the bond issuer for wildfire resilience insurance debris removal and slope stability / debris removal use cases (use cases (i) and (ii), respectively). For the wildfire resilience insurance use case for a private timber owner (use case (iii)), the bond issuer would be the timber company. And for the residential insurance saving scenario, the bond issuer would be the local government entity (i.e., city, county, special district, etc.) or multiple local government entities whose homeowners are benefitting from reduced residential insurance pricing as a result of ecological forestry. In this case, the local government(s) could assess a fee on homes equal to or less than the insurance savings, so as to capture some or all of the insurance savings and apply it toward the debt service on the bonds.

We also assume, for purposes of this analysis, that the premium savings associated with each of the use cases or types of wildfire resilience insurance persist for 10 and 15 years, respectively. We recognize that a number of variables including changes in the background wildfire risk could significantly affect the premium and premium savings over this period of time. We note, however, that our assessment of changes in overall wildfire regime in Californian forestlands attributable to climate change in the parametric insurance analysis supports much other published work that points to a rapid increase in overall wildfire hazard. This in turn, and all else being equal, would result in greater benefits accruing in the future from ecological forestry and, therefore, increasing benefit to cost ratios.

The table provided on the next page outlines the amount of bond funding and resulting forest treatment acreage which can be supported by the insurance premium savings associated with each of the insurance use cases or scenarios in the manner described above. It shows each of the use cases scenarios discussed in the previous section that include ecological forestry.

Bond Financing for Forest Treatment

10-year						
Scenario	Issuer	Interest rate	Bond amount ($M)	Treatment costs ($M)	Acres treated	% Treatment cost offset by insurance savings
1b	PCWA	1.25%	0.37	12.2	366	3%
2d	PCWA	1.25%	0.68	12.2	676	6%
3b	Timber owner	2.2%	3.38	28.0	3,382	13%
4	Municipality	1.25%	197.31	194.4	197,309	108%
15-year						
Scenario	Issuer	Interest rate	Bond amount ($M)	Treatment costs ($M)	Acres treated	% Treatment cost offset by insurance savings
1b	PCWA	1.5%	0.52	12.2	524	5%
2d	PCWA	1.5%	0.97	12.2	967	9%
3b	Timber owner	2.8%	4.83	28.0	4,833	19%
4	Municipality	1.5%	281.92	194.4	281,920	162%

For all scenarios except 3b, current municipal bond interest rates are used, although for 1b and 2d it would be PCWA that issues the bond. The interest rate is assumed to increase with duration of the bond and the rates used here are broadly representative of municipal bond rates paid in the state of California - bonds maturing in 10 years pay a 1.25% interest rate, while 15-year bonds pay 1.5%.[114]

Scenario 3b considers the case of a hypothetical private timber owner and therefore uses the current average (High Quality Market) corporate bond rate. The interest rates are higher than the municipal bond rates; they are 2.2% and 2.8% for 10 and 15 years, respectively.[115]

Given the known monthly premium savings, the amount of the bond is calculated using:

Loan amount =
Monthly premium savings / discount factor

where the discount factor (D) is a function of the monthly interest rate (r) and number of monthly payments (n):

$$D = \{(1 + r) ^\wedge n - 1\}/\{r (1 + r) ^\wedge n\}$$

The right-most column in the table above shows the percentage of total treatment costs that can be offset by the sum of (non-discounted) annual premium savings that accrue due to the ecological forestry program. The longer the treatment is effective, the more opportunity there is for premium savings to offset treatment costs.

For three of the four scenarios considered here, even assuming a 15-year duration for treatment, the percentage contribution of premium savings to total ecological forest treatment costs are modest. Scenario 1b only covers 3% (5%) for a 10- / 15-year period, while Scenario 2d is nearly twice as effective with 6% (9%) over 10 / 15 years. Scenario 3b offers more substantial savings of 13% (19%). Scenario 4 is the only one in which premium savings can more than offset the treatment costs with 108% (162%) offset over a 10- / 15-year period.

These results highlight the importance of multiple insureds purchasing wildfire resilience insurance which accounts for ecological forest treatment, and then contributing the premium savings to finance the cost of ecological forest treatment. For example, in the case of Scenarios 1b and 3b where the water and power agency is the purchaser of a wildfire resilience parametric insurance product, several purchasers of the insurance with associated premium savings would be needed to finance more of the costs of ecological forestry associate with the premium savings. We

114 https://www.municipalbonds.com/; April 2021
115 US Treasury Department, April 2021

note here that, while we have looked only at a single user of parametric insurance to manage wildfire risk in a particular forest stand, in reality there are multiple entities and institutions which benefit from any area of forest. This suggests that the per-acre value assigned to the parametric pay-out and, therefore, the scale of coverage and of premium savings, could be many multiples of that used in our parametric insurance case studies.

Comparing the premium savings by scenario from the previous section to the bond size in the table above, one sees that higher premium savings translate to a higher bond amount that can be financed. For each bond duration, the table indicates that both bond amount and acres treated using bond funding increase from top to bottom. For example, comparing Scenarios 1b and 3b, one sees that a nearly 10-fold increase in premium savings ($39,000 vs. $360,000) translates to an equivalent difference in bond amounts ($0.37 million vs. $3.38 million). Likewise, the acres treated increase from 1b (366 acres) to 3b (3,382 acres), although by slightly less than a factor of 10 since the area treated depends on treatment costs and the area to be treated, which vary by scenario. The treatment costs follow from the area treated and length of time the treatment is needed for. Also note that for the range of values considered here, each scenario sees an increase in bond amount and acres treated as the duration of the bond is extended. For example, Scenario 4 shows that the bond amount increases from approximately $197 million to approximately $282 million as the duration increases from 10 to 15 years. Similarly, the area which can be treated increases from almost 197,000 acres to approximately 282,000 acres.

We note that benefits should increase over longer time periods, as successive ecological forestry interventions are likely to be cheaper on a per-acre basis.

5.5 Community Based Catastrophe Insurance Concept Provides Opportunity to Capture Premium Savings and Invest in More Ecological Forestry

One way in which residential insurance premium savings resulting from ecological forestry might be captured, and then applied toward the funding of ecological forest treatment projects, is through a new insurance product which several insurers are exploring — "community based catastrophe insurance" or "community based insurance" (Bernhardt et al., 2021[116]). This concept is being driven in part by the increasing unavailability of private home insurance for homes facing moderate or high wildfire risk in California (see discussion below). Insurers are exploring whether something akin to a "group insurance policy" might be written for a community. The local government would purchase the community-based insurance directly to cover homes in that community and then collect a proportionate fee from homeowners, whose homes are covered, to pay for the community-based insurance.

A community-based insurance product could be modelled, structured, and priced to account for the risk reduction benefit of ecological forestry. Based on the results of this study, the price for a community based insurance product which accounts for ecological forestry that reduces wildfire risk for the community should be lower than the aggregate cost of individual residential home insurance within the community where ecological forestry has not been undertaken. The price savings could be passed on in its entirety to the homeowners through a lower charge for each homes' respective share of the community-based coverage. Alternatively, some portion of the price savings could be captured or retained by the local government purchasing the insurance and used to finance investments in ecological forestry.

For example, if there were a community within or adjacent to forest lands where ecological forestry treatment would reduce fire risk, and that work had not yet been undertaken, the initial price of the community-based insurance for the local government to cover homes in the community would be higher than it would otherwise be if ecological forestry were undertaken and accounted for in the insurance modeling, structuring and pricing. And the aggregate cost of individual home insurance in the community would also be higher than the cost of community-based insurance where ecological forestry has been undertaken. The insurer offering community-based insurance could project over time, as ecological forestry is undertaken, what the price savings would be for the community-based insurance. The local government could take the net present value of those savings over time and issue a bond to fund some portion or all of the ecological forestry work, and use the premium savings over time to pay for some or all of the debt service for the bond, similar to the residential scenario discussed in Section 5.4.

Community-based insurance provides an opportunity to account in insurance pricing for the community-wide risk reduction benefit of ecological forestry when undertaken at landscape scale. While community-based insurance is not currently available in the market, the fact that several insurers are working to develop it, coupled with the ongoing decline in availability of individual home insurance, increases the likelihood that it will be brought to market. We are likely to see community-based insurance pilot projects in California. With the results in hand from this study, there should be an opportunity to pilot a community-based insurance product which accounts for the risk reduction benefit of ecological forestry, and which can also test how the premium savings might be captured and invested in an associated ecological forest treatment project.

5.6 Ecological Forestry at Scale Reduces Home Insurance Premiums and Is Important Part of Solution to Keep Home Insurers Writing Insurance in WUI

Private home insurance for homes in California facing wildfire risk is not only becoming more expensive, it is also becoming increasingly unavailable. As noted earlier in this paper, the financial losses arising from wildfire are increasingly so large and variable that insurance is increasingly unobtainable, leaving governments, business, and individuals to bear the risk and loss associated with wildfires. The results of this study indicate that ecological forestry is an important part of the solution to keep private home insurance available in those areas of California facing wildfire risk.

As private home insurance becomes increasingly unavailable for homes facing wildfire risk in the WUI, homeowners are forced to obtain fire insurance from California's FAIR Plan[117]. The California FAIR plan is a consortium of private insurers established by statute to issue a fire insurance policy for any California homeowner who is unable to obtain private home insurance. The FAIR Plan is not taxpayer funded nor are its rates subsidized. By state law, the FAIR Plan must set its rates actuarially based on the actual risk faced by its policyholders. As a result, FAIR Plan policies are typically more expensive than private home insurance because FAIR Plan policyholders are those where the risk is such that private insurers have declined to renew or write insurance for those homes. For example, a homeowner who paid $1,200 a year for private home insurance may see a 300% increase to $3,600 a year for a FAIR Plan policy.

From 2018 to 2019, there was a 36% increase in FAIR Plan policies written state-wide in California. In those zip codes with homes facing a moderate to very high fire risk, there was a 112% increase in FAIR Plan policies written for homeowners. In the 10 counties with the highest exposure of homes to high and very high fire risk, there was a 559% increase in FAIR Plan policies written for homeowners.

The results of the Wildfire Resilience Insurance Project demonstrate that the wildfire risk reduction associated with ecological forestry can not only be accounted for in insurance modeling and structuring, but that it also results in a significant decrease in expected losses and a related decrease in insurance pricing.

The quantification of home insurance premium savings associated with ecological forestry in PCWA's watershed provides compelling evidence that ecological forestry is a critical part of the solution to keep private home insurance available in the areas of California facing wildfire risk. This study demonstrates how the risk reduction benefit of ecological forestry can be accounted for in a wildfire risk score model. Home insurers in California are using wildfire risk score models to decide whether to renew or write new home insurance for homes facing wildfire risk. The risk reduction benefit of ecological forestry as demonstrated in this study should be accounted for, where it is occurring, in the wildfire risk score models used by insurers to determine whether to renew or write new home insurance.

Insurers and catastrophe modeling firms who license wildfire risk score models for insurers should incorporate the findings of this study in their wildfire risk score models. This will enable homes, whose wildfire risk is reduced due to ecological forest treatment, to see the benefit of that risk reduction in the risk score assigned to the home by the wildfire risk score model used to determine whether or not to renew or write insurance for the home. Both private home insurers and the FAIR Plan should incorporate the findings of this study in their rate development and modelling, so that where ecological forestry is occurring at landscape scale rates for both the FAIR Plan and private home insurance will take into account the risk and expected loss reduction benefits of ecological forestry.

116 Bernhardt A., Kousky, C., Read, A., and Sykes, C. 2021. Community-Based Catastrophe Insurance: a Model for Closing the Disaster Protection Gap. New York City, New York, Marsh & McLennan Companies.

117 https://www.cfpnet.com/. "The California FAIR Plan Association was established in 1968 to meet the needs of California homeowners unable to find insurance in the traditional marketplace."

5.7 Insurance Premium Savings Associated with Ecological Forestry can Incentivize National, State, and Local Policymakers to Appropriate More Funds for Ecological Forestry and Encourage Private and Public Asset and Property Owners in or Adjacent to Forests to Fund Ecological Forestry Projects

Additional funding is needed to meet the US Forest Service's and state of California's goals with regard to expanding ecological forest treatment on public and private forest lands, including national forest lands. Policymakers at the national, state, and local level face competing demands for public funds. Demonstrating that ecological forestry reduces insurance pricing for public and private property and asset owners in and adjacent to forests, including home insurance pricing, provides a compelling additional economic reason for national, state, and local policymakers to increase funding for ecological forest treatment on forest lands, including national forests.

In addition, demonstrating an insurance benefit from ecological forestry can also provide a further incentive for private and public asset owners in or adjacent to forests lands, to contribute to funding ecological forestry projects that will reduce the risk of wildfire and consequent damages to their assets and facilities. For public water and power utilities in or adjacent to forest lands, lower insurance pricing for parametric insurance products, or lower indemnity insurance pricing for structures vulnerable to fire like the buildings owned by the PCWA, are an additional reason to participate in funding ecological forestry projects in their watershed.

The Wildfire Resilience Insurance project and study demonstrate that ecological forestry can reduce insurance premiums for public and private owners of assets and property in or adjacent to forest lands facing a risk of wildfire, including home insurance premiums. Moreover, as discussed above, these results demonstrate that ecological forestry is a critical part of the solution to help keep private home insurance available in California's WUI. Taken together, the results provide an additional compelling reason for national, state, and local policymakers to increase appropriations for ecological forestry projects in national and other forest lands.

Prescribed fire and thinning crew. © Aaron Schmidt

Section 6: Recommendations

1. **Federal, state and local policymakers** should increase substantially funding for ecological forestry in national and other forest lands. New fire scenario modeling from the US Forest Service suggests that targeted treatments on approximately 51 million acres of federal, state, tribal and private lands nationally in the next 10 years will significantly reduce exposure in the highest risk areas[118]. A recently released report found that a minimum investment of approximately $5-6 billion per year over the next 10 years is needed for the highest priority work to reduce wildfire risks across federal, tribal, state and private lands, and for community and infrastructure investments[119].

2. **Insurance regulators** should encourage insurers and insurance risk modelers to consider the results of this study and to incorporate its results in their underwriting and pricing of insurance. If not currently permitted by state law or regulation, insurance regulators or policymakers should consider modifying rate approval regulations to allow insurers to account for ecological forestry in rate development.

3. **Insurers and risk modelers** should consider incorporating the findings and methodology presented in this study in their wildfire risk score models, so that homes and businesses for whom ecological forestry reduces wildfire risk see the benefit of that risk reduction in the risk score assigned to them, which is used to determine whether or not to renew or write insurance for the asset.

118 House Appropriations Subcommittee on Interior, Environment, and Related Agencies Hearing on U.S. Forest Service FY2022 Budget Request, response by USDA Forest Service Chief Victoria Christiansen, April 15, 2021.
119 "Wildfire Resilience Funding: Building Blocks for a Paradigm Shift" May 2021, The Nature Conservancy.

4. **Private home insurers and the California FAIR Plan**[120] should consider incorporating the findings of this study in their rate development and modeling, so that where ecological forestry is occurring at landscape scale, rates for both the FAIR Plan and private home insurance will take into account the risk and expected loss reduction benefits of ecological forestry.

5. **Businesses and agencies with assets or property** in or adjacent to forests should pilot wildfire resilience insurance. Water and power agencies with facilities in forests should consider piloting wildfire resilience insurance. Private timber companies whose lands are or will be ecologically managed or whose assets are in or adjacent to national or other forests where ecological forestry is occurring are another potential for a pilot wildfire resilience insurance project. Ski resorts with commercial and/or residential structures vulnerable to wildfire may also present an opportunity to pilot wildfire resilience insurance while contributing insurance premium savings to fund or finance ecological forest treatment in adjacent national or other forests.

6. **Residential communities** adjacent to or in national or other forest lands undergoing ecological forestry also present an opportunity to pilot a community based wildfire resilience insurance product, and to use insurance savings captured through a property fee or assessment on homeowners to pay debt service on bonds issued to finance ecological forest treatment.

7. **Public owners of forest lands such as USFS, the Bureau of Land Management, National Park Service and the California State Parks Department** should use the findings in this report to encourage federal, state and local policymakers to provide more funding for ecological forestry projects.

120 https://www.cfpnet.com/. “The California FAIR Plan Association was established in 1968 to meet the needs of California homeowners unable to find insurance in the traditional marketplace”.

There are an estimated 4 million homes in California in the Wildland Urban Interface with moderate or high risk of wildfire, like these in Vacaville, Solano County. © Robert Couse-Baker/Creative Commons

Section 7: Conclusion

The results of this study demonstrate that ecological forestry can be accounted for in insurance modeling and pricing.

Insurers and catastrophe modeling firms who license wildfire risk score models for insurers should incorporate the findings of this study in their wildfire risk score models. This will enable homes, whose wildfire risk is reduced due to ecological forest treatment, to see the benefit of that risk reduction in the risk score assigned to the home by the wildfire risk score model used to determine whether or not to renew or write insurance for the home. Both private home insurers and the California FAIR Plan should incorporate the findings of this study in their rate development and modeling, so that where ecological forestry is occurring at sufficient scale, rates for both the FAIR Plan and private home insurance will take into account the risk and expected loss reduction benefits of ecological forestry.

A next step would be to pilot a wildfire resilience insurance product with commercial or public property or asset owners or a community, where ecological forestry has or will occur such that the risk of severe wildfire is reduced.

Water and power agencies located in national or other forest lands in the western United States, where ecological forest treatment is occurring so as to reduce wildfire risk in some or all of their watershed, present one such opportunity to pilot wildfire resilience insurance. Private timber companies whose lands are or will be ecologically managed, or whose assets are in or adjacent to national or other forests where ecological forestry is occurring, present another potential for a pilot project. Ski resorts with commercial and/or residential structures vulnerable to wildfire may also present an opportunity to pilot wildfire resilience insurance, while contributing insurance premium savings to fund or finance ecological forest treatment in adjacent national or other forests.

Another opportunity to pilot wildfire resilience insurance might be asset or property owners who are issuing a forest conservation bond like that piloted by Blue Forest Conservation[118]. Wildfire Resilience Insurance might be piloted as an adjunct to complement a forest conservation bond.

Residential communities adjacent to national or other forest lands undergoing ecological forest treatment also present an opportunity to pilot a community-based wildfire resilience insurance product, or to otherwise capture residential insurance premium savings through a property fee or assessment on homeowners, whose insurance price will be lower due to ecological forest management.

This is not an exhaustive list but is indicative of the potential opportunities to pilot wildfire resilience insurance where ecological forest treatment is occurring, coupled with capturing the insurance premium savings to fund or finance ecological forest treatment.

118 https://www.blueforest.org/forest-resilience-bond

Appendix A: Willis Re Wildfire Risk Score Model

The Willis Re tool employs the U.S. Forestry Service's (USFS) most recent simulation of over 50,000 years of probabilistic data (Short et al., 2020[119]) as well as published research from the National Fire Protection Association,[120] the U.S. Department of Agriculture, and others to develop a scoring methodology that identifies structures within the state that are at high risk to wildfire.

The methodology follows seven distinct steps in order to arrive to a gridded wildfire risk assessment score on a 10-meter resolution grid for the entire state of California.

1. Determine the frequency of large wildfires using the USFS probabilistic simulations;
2. Adjust intensities for deficiencies in current wildfire models when considering crown fires;
3. Adjust weights so that some wildfires can be suppressed relative to others based on vegetation type;
4. Account for small wildfire risk using an historical wildfire occurrence database;
5. Use wildland urban interface (WUI) data to adjust risk score based on distance between structures and nearest wildfire risk;
6. Apply the scoring algorithm to determine the wildfire risk score for the entire State of California; and
7. Calibrate the model using an industry exposure database.

1. Probabilistic Simulation of Wildfire Potential

In order to determine, in a probabilistic fashion, the likelihood and intensity of wildfire occurrence over the state of California, the Fire Simulation System's (FSim, Figure A-1) output is employed. FSim, which is developed by the USFS, was produced to create estimates of the probabilistic components of wildfire risk, and produces spatial surfaces of burn probability and the conditional probability of six fire intensity levels defined by flame length classes (0 to 2 ft, 2 ft to 4 ft, 4 ft to 6 ft, 6ft to 8ft, 8 ft to 12 ft, and greater than 12 ft). These outputs are created for all lands within the state.

The simulation models daily ignitions over 50,000 contemporary fire seasons (i.e., not future projections), given statistically possible weather conditions based on observations from recent decades, on a 270m x 270m grid. In addition to probabilistic ignition FSim simulates the growth and spread of wildfire using a deterministic fire propagation and suppression model to simulate the evolution of fires started by the probabilistic component of the model. Inputs to this element of the simulation include (but are not limited to):

- Fuels (vegetation type)
- Slope
- Moisture
- Wind
- Weather

The proportion of times that a particular pixel burns within a given flame length provides the conditional flame length probability for that flame length class. FSim has six conditional flame lengths; for this model we aggregated them into four classes: 0 to 4 ft, 4 to 8ft, 8 to 12 ft, and > 12 ft. The actual burn probability of a burn class is the product between the conditional probability of each of our four flame length classes by the total burn probability (Dillon et al., 2015)[121].

In order to combine the flame length intensity grids together, weightings of the relative contribution of each flame length band to the overall wildfire risk need to be assessed. This is achieved by leveraging existing mathematical relationships between flame length intensity and fire line intensity (Andrews et al., 2011)[122]. Flame length band 0 to 4ft is used as the baseline intensity and each band is given a relative weight. Each flame length conditional probability surface is multiplied by the total burn probability as well as the relative weight. Finally, all grids are summed together to give the total weighted contribution of wildfire risk across the model domain.

119 Short, K.C., Finney, M.A., Vogler, K.C., Scott, J.H., Gilbertson-Day, J.W., and Grenfell, I.C. 2020. Spatial datasets of probabilistic wildfire risk components for the United States (270m). 2nd Edition. Fort Collins, Colorado, Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2016-0034-2
120 https://www.nfpa.org/
121 Dillon, G.K., Menakis, J., and Fay, F. 2015. Wildland fire potential: A tool for assessing wildfire risk and fuels management needs. In: Keane, R.E., Jolly, M., Parsons, R., and Riley, K. Proceedings of the large wildland fires conference; May 19-23, 2014; Missoula, MT. Proc. RMRS-P-73. Fort Collins, Colorado, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 60-76.
122 Andrews, P.L., Heinsch, F.A., and Schelvan, L. 2011. How to generate and interpret fire characteristics charts for surface and crown fire behavior. Gen. Tech. Rep. RMRS-GTR-253. Fort Collins, Colorado, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://doi.org/10.2737/RMRS-GTR-253

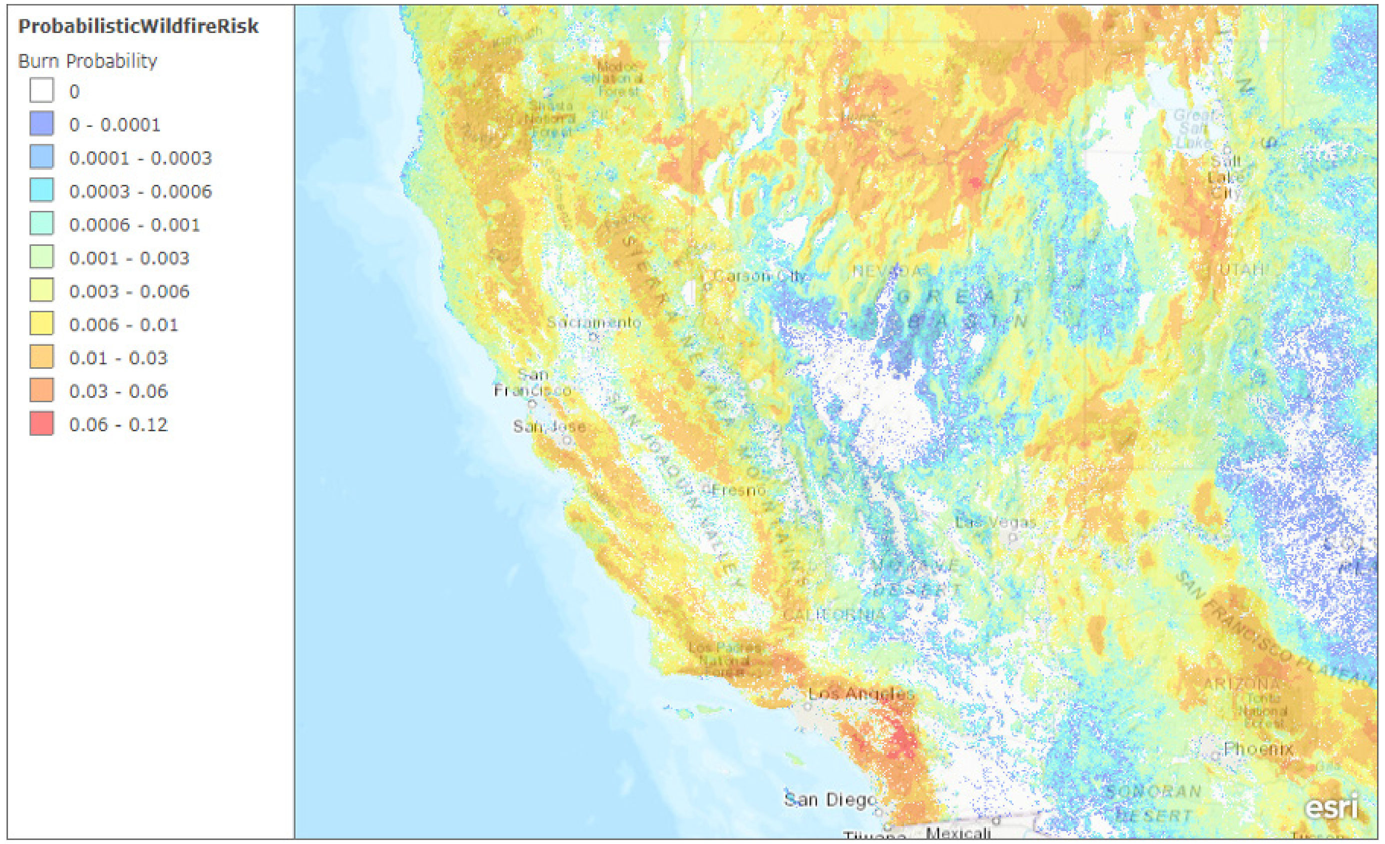


Figure A-1. FSim 2017 Simulation, Annual Burn Probability.[123]

The FSim simulation stochastic and probabilistic approaches have been modified and re-run as the input data sets are updated and the methodology is refined to reflect new research. The rating methodology uses the most recent outputs available at the time of development which were released in 2017 (Short, 2017)[124].

2. Application of Crown Fire Weights

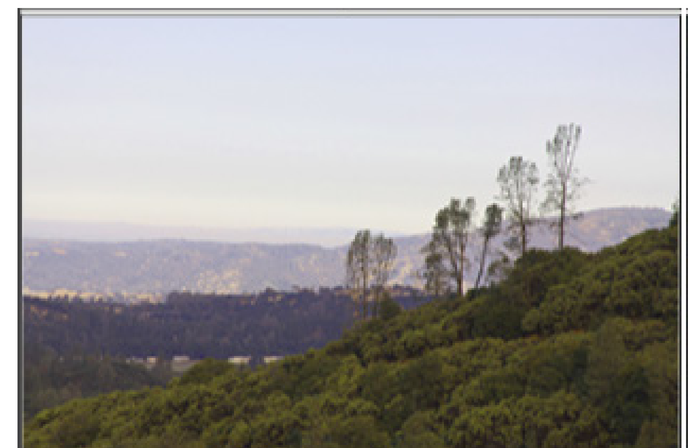
While crown fires are modeled within FSim to the extent that current fire spread models are capable the flame lengths produced represent surface fire flame lengths and as a result underrepresent the flame lengths that occur during a crown fire event. In order to account for this effect regions with a heightened risk of crown fire based on the profile of the vegetation are identified and weighted accordingly. To achieve this first closed canopy forests were identified based on the following criteria: forest canopy height >16 ft and forest canopy cover >50%. In both cases the most recent data sets from the USDA and the United States Geological Service (USGS) joint program "LANDFIRE" were employed[125]. Within these closed canopy forests the following criteria were employed to identify regions with crown fire capacity: flame length for the conditional probability class was greater than zero and the flame length overlapped the crown base height. Having applied this on a pixel by pixel basis a mask of regions with high crown fire risk was identified.

Acknowledging that chaparral vegetation types such as California Chaparral are also at high risk of producing crown fires (Figure A-2) another mask was created to identify chaparral pixels using the LANDFIRE Existing Vegetation Type (LANDFIRE, 2017) data set and further limited these to only those pixels with greater than 30% shrub cover. To determine appropriate weights to apply to these regions established relationships between the flame length intensity of crown fires (typically 20 ft to 80 ft) were leveraged and the average fire line intensity within the range assessed (Figure A-3). This resulted in a weight of 130 i.e., 130 times more intense than 0 to 4 ft surface fires. In pixels where crown fire potential had been deemed to occur, we multiplied the conditional probabilities by 130 for the flame lengths deemed sufficient to ignite a crown fire and replaced the previously applied surface weights.

At this point the resulting surface no longer represents probabilities but a dimensionless index of large wildfire potential.

Chamise chaparral in San Benito County, CA. Photo © Neal Kramer, used with permission.

Redshank chaparral in Riverside County, CA. Public domain image by Anthony Baniaga.



Mixed chaparral (sticky whiteleaf manzanita-canyon live oak-toyon-gray pine) in Columbia, CA. USDA, Forest Service photo by Janet Fryer.

Montane chaparral (greenleaf manzanita-prostrate ceanothus, in center foreground) surrounded by montane mixed-confier forest (background) in Tuolumne County, CA. USDA, Forest Service photo by Janet Fryer.

Figure A-2. Types of California Chaparral[126]: Chamise-redshank chaparral occurs on low foothills; buckbrush often co-dominates in chamise chaparral. Mixed chaparral occurs on foothills and is typically co-dominated by ceanothus, manzanita, and/or scrub oak species. Montane chaparral occurs at mid elevations and is typically co-dominated by ceanothus and manzanita species (Estes, 2016).

123 Available from USFS, e.g., https://www.firelab.org/project/fsim-wildfire-risk-simulation-software
124 Short, Karen C. 2017. Spatial wildfire occurrence data for the United States, 1992-2015 [FPA_FOD_20170508]. 4th Edition. Fort Collins, Colorado, Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2013-0009.4
125 LANDFIRE. 2017. Existing Vegetation Cover; Existing Vegetation Type; Forest Canopy Base Height. U.S. Department of Agriculture and U.S. Department of the Interior. https://landfire.gov/
126 https://www.fs.fed.us/database/feis/fire_regimes/CA_chaparral/all.html

3. Application of Resistance to Control Weights

In order to account for the ease of which wildfires in some vegetation types can be contained relative to others current research of suppression efficacy was employed (Table A-1). By taking the inverse of the rate at which a fire line can be produced during initial attack by hand crews we can identify vegetation types for which the rate of control is lower than the reference vegetation class (conifer) which is set to 1. As the purpose of this adjustment is primarily to reduce the wildfire score in classes that are relatively easier to contain, we only adjust for values where the resistance to control is less than 1. These vegetation classes are scaled pixel by pixel by the appropriate rate, producing a raw unscaled score for large wildfires. The score is then scaled from 0 to 10 and is heretofore called the Large Wildfire Potential (LWP).

Table A-1. Resistance to Control Weights (Dillon et al., 2015)[127].

Derivation of weights based on fireline intensities for surface fires.

Surface flame length (ft)	Fireline intesity (Btu/ft/s) [a]	Average intensity	How many "times as intense" as < 4 ft flames?	Weighting used
1	5.67	31.03	1.0	1
2	25.60			
3	61.82			
4	115.53	243.03	7.8	8
5	187.67			
6	278.95			
7	389.99			
8	521.34	770.86	24.8	25
9	673.48			
10	846.84			
11	1,041.80			
12	1,258.73	2,430.67	78.3	75
13	1,497.97			
14	1,759.82			
15	2,044.59			
16	2,352.55			
17	2,683.95			
18	3,039.06			
19	3,418.10			
20	3,821.31			

127 Dillon, G.K., Menakis, J., and Fay, F. 2015. Wildland fire potential: A tool for assessing wildfire risk and fuels management needs. In: Keane, R.E., Jolly, M., Parsons, R., and Riley, K. Proceedings of the large wildland fires conference; May 19-23, 2014; Missoula, MT. Proc. RMRS-P-73. Fort Collins, Colorado, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 60-76.

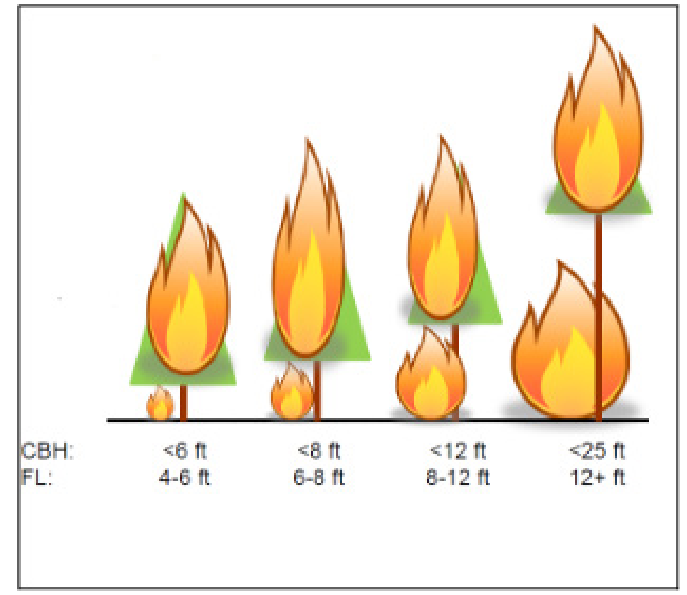


Figure A-3. Relationship of crown base height and flame length in assessing crown fire risk (Dillon, et al., 2015).

4. Small Wildfire Potential

FSim focuses on large wildfires because they are responsible for burning over 90% of the total acres burned within the USA. They are also overwhelmingly the primary driver of insured losses due to wildfire given their intensity and the difficulty of suppression. Given this focus on large wildfires areas that are subject to frequent small fires are underrepresented in the results of the simulation. In order to provide an appropriate weight to these regions an ignition surface for small wildfires is computed from the Fire Occurrence Database produced by the USDA (Short, 2017)[128]. The version of the database used covers ignitions from 1992-2015.

Using the attribute information supplied with the spatial data fires over 300 acres were removed to avoid double counting fires simulated by the LWP. As the data is spatially represented as ignition points a kernel density function was used to create a continuous surface of fire ignitions. As with the LWP we normalize the values of the ignition density surface on a 0 – 10 scale to create the Small Wildfire Potential (SWP) surface.

5. Distance to the Wildland Urban Interface (WUI)

The Martinuzzi WUI dataset (Figure A-4, Martinuzzi et al., 2015[129]) employs US Census Block data and the National Landcover Database to identify census blocks of sufficiently dense housing that meet or intermingle with undeveloped wildland vegetation. Employing the definition of 6.17 housing units per square kilometer set by the Federal Register census blocks from the 2010 Census meeting the threshold housing density threshold are identified. Using the National Landcover Database (NLCD), a high-resolution land use data set produced using 30-meter Landsat TM data a surface is created by limiting the land use types to only vegetation classes. The total area of vegetation within each census block meeting the threshold density of housing is calculated. Census blocks with greater than 50% vegetation by area are defined as intermixed wildland-urban interface (WUI) zones. Census blocks with less than 50% vegetation but deemed to be within 2.4km of a heavily vegetated region (greater than 75% vegetated) are deemed to be interface WUI regions (Martinuzzi et al., 2015)[130].

128 Short, Karen C. 2017. Spatial wildfire occurrence data for the United States, 1992-2015 [FPA_FOD_20170508]. 4th Edition. Fort Collins, Colorado, Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2013-0009.4
129 Martinuzzi, S., Stewart, S.I., Helmers, D.P., Mockrin, M.H., Hammer, R.B., and Radeloff, V.C. 2015. The 2010 wildland-urban interface of the conterminous United States. Research Map NRS-8. Newtown Square, PA, U.S. Department of Agriculture, Forest Service, Northern Research Station. https://doi.org/10.2737/NRS-RMAP-8
130 Martinuzzi, S., Stewart, S.I., Helmers, D.P., Mockrin, M.H., Hammer, R.B., and Radeloff, V.C. 2015. The 2010 wildland-urban interface of the conterminous United States. Research Map NRS-8. Newtown Square, PA, U.S. Department of Agriculture, Forest Service, Northern Research Station. https://doi.org/10.2737/NRS-RMAP-8

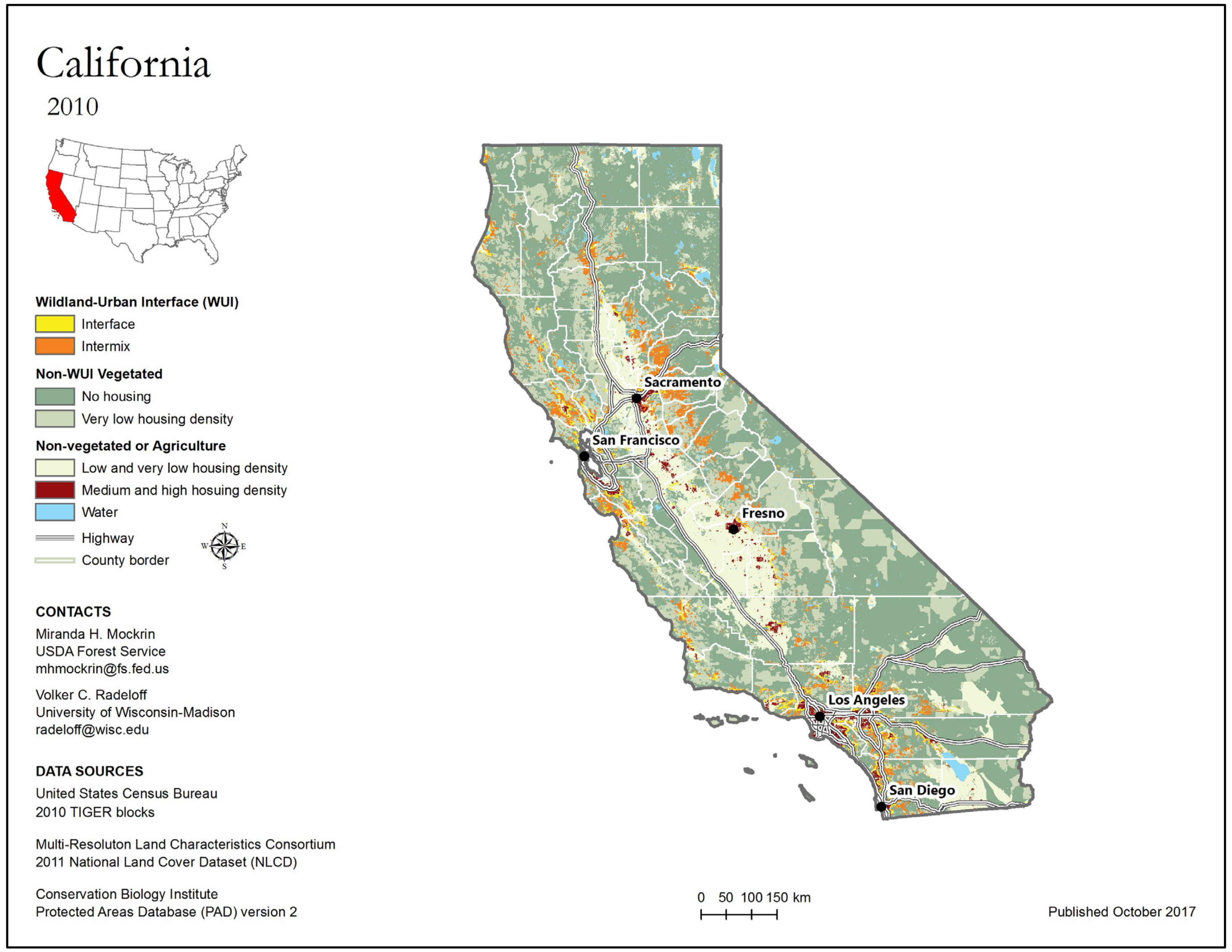


Figure A-4. California wildland-urban interface (WUI) Map (Martinuzzi et al., 2015)[131].

Acknowledging that wildfire losses can occur well within the urban environment a surface is derived at a 10 square meter grid from the data set that calculates the distance from any built-up area and the nearest WUI zone. This surface can be queried to determine if a location is in an intermixed WUI zone, an interface WUI zone, a vegetated region or the distance from this location the nearest WUI zone. The resulting surface is referred to as the Distance to Wildland Urban Interface (DWUI).

131 Martinuzzi, S., Stewart, S.I., Helmers, D.P., Mockrin, M.H., Hammer, R.B., and Radeloff, V.C. 2015. The 2010 wildland-urban interface of the conterminous United States. Research Map NRS-8. Newtown Square, PA, U.S. Department of Agriculture, Forest Service, Northern Research Station. https://doi.org/10.2737/NRS-RMAP-8

6. Scoring Algorithm

A key limitation of the FSim simulation is that the simulated fires are extinguished once they encounter a "non-burnable fuel class" where this definition includes most built up areas and an extremely high proportion of structures within the state. Other products that have employed its output in wildfire risk management and have had significant struggles correlating with claims data from historical fires for this reason. To avoid this issue when a given location (commonly passed as a latitude/longitude pair) is evaluated the first step is to determine the LWP value of the closest vegetated location (CLWP). The other values area gathered from the surfaces described are assessed at the grid cell that encompasses the point.

The first step is to calculate the Total Wildfire Score (TWS) which represents the wildfire risk of the vegetated region nearest the risk (or in the case of vegetated regions at the location). The TWS is computed as:

$$TWS = CLWP * 0.8 + SWP * 0.2$$

Next the DWUI value is evaluated. If the risk is in the Intermixed WUI TWS is scaled by 2. If the location is in the interface it is scaled by 1.3. If the risk is in heavily vegetated areas TWS is scaled by 1.3. If the DWUI is a distance to the interface of intermix a linear decay function is applied such that the TWS of the nearest heavily vegetated area decays away to 0 at 2km. This 2km value is based on the published estimate of the furthest distance a firebrand can be expected to propagate.

```
If DWUI = vegetated
WFS = TWS * 2
Else if DWUI = intermix
WFS = TWS * 1.3
Else if DWUI = interface
WFS = TWS * 1.3
Else if DWUI = distance
WFS = Apply linear decay to TWS
```

7. Remapping the Distribution of the Score

For the score to be meaningful it must successfully identify high risk wildfire structures without producing a high false positive rate which would result in unfairly penalizing low risk structures. Similarly, the values returned by the score need to be tangible enough that an end user of the methodology can easily determine what the values represent with respect to the total distribution of scores within the state. The first step in normalizing the distribution of the score is to use a database of over 10 million structure locations within the state and compute the raw score for each structure.

From this an empirical CDF is computed and the raw score's distribution examined. The raw score has a distribution heavily skewed to lower values; this is an expected result as most structures within the state are beyond the 2km distance threshold to a WUI region. The distribution is then remapped to a continuous distribution from 0–4.

Appendix B: Parametric Product Historical Analysis

Table B-1 provides a list of the largest 10 fires in our analytical dataset.

Table B-1. MTBS-defined burn area severity for the largest 10 fires between 1984 and 2018 across the Northern Sierra Nevada pyrome. The fires are ordered from largest total burned area to smallest total burned area. The total burned areas indicate the sum of 155 fires. The Willis Towers Watson-defined severity classifications (Low, High) are indicated, alongside the original MTBS sub-classifications (Unburned-low, Low, Moderate and High). The acres presented are not climate adjusted (see discussion below). The climate adjustment multiplication factor is included.

Fire information		Total burned area severity (acres)					Climate adjustment multiplication factor
		Low (WTW)		High (WTW)			
Name	Year	Unburned-Low (MTBS)	Low (MTBS)	Moderate (MTBS)	High (MTBS)	Total	
RIM	2013	48,181	82,854	73,085	51,125	255,245	1
CAMP	2018	42,686	55,820	38,556	15,245	152,307	1
KING	2014	9,557	26,142	19,990	43,206	98,895	1
FERGUSON	2018	11,527	42,000	33,083	8,573	95,183	1
DETWILER	2017	26,102	37,467	17,625	1,112	82,306	1
CHIPS	2012	9,673	30,765	23,688	15,619	79,745	1
BUTTE	2015	9,319	17,855	27,524	16,764	71,462	1
MOONLIGHT	2007	6,562	13,917	16,471	28,486	65,436	3
ACKERSON COMPLEX	1996	6,346	32,108	12,484	7,160	58,098	3
BTU LIGHTNING COMPLEX (LONG BRANCH-JACK)	2008	8,663	16,127	14,374	12,429	51,593	3
Total (all fires)		**398,646**	**723,809**	**590,320**	**429,110**	**2,141,885**	

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