Wildfire Resilience in Western North America:
Progress and Priorities

MARCH 2022

GORDON AND BETTY
MOORE
FOUNDATION

1. FOREWORD

The Gordon and Betty Moore Foundation started to focus its activities on wildfire following the 2017 California fire season, which was the most destructive fire season on record at the time. The Foundation recognized the need for accelerated solutions to a growing and worsening fire problem. A small workshop in April of 2019 identified what could be done technically and socially to cope more effectively with fire. It identified interventions at the different phases of fire:

- In the **pre-fire** phase focused on prevention.
- At the **fire occurrence** phase focused on immediate response.
- At the **mature fire** phase focused on containment and mitigation.
- For the **post-fire** phase focused on recovery and remediation.

The focus of the Foundation activities has been on upstream solutions, at the pre-fire and early fire phases. It recognized that making a trade-off between these phases is a flawed approach, as the stages are interconnected and there are opportunities to improve at each stage.

Progress is promising, while at the same time, urgency has only increased and there is no time to lose. We understand that to reduce the threat of wildfire will require strategies that span decades with incremental improvements, whereas in other aspects of wildfire, rapid progress can be made, and solutions applied during the next fire season. We recognize that activities on wildfire are often siloed and there are gaps in communication, the data needed and information exchange.

Since 2019, new programs and initiatives have been launched and there are powerful actors in managing and adapting to wildfire in the federal and state government, as well as the private sector. However, the landscape of fire activities remains largely fragmented and further coordination amongst programs and initiatives is needed. Philanthropy can augment and contribute to addressing the wildfire problem by its speed to initiate activities, its tolerance to take risks and the flexibility to provide resources in a variety of forms and mechanisms and in the diversity of organizations, groups and individuals it can fund and support to work together with a long-term perspective.

A concerted effort is now needed to address the societal challenges of wildfire, harnessing the comparative advantages of what can be done by government, private sector, non-governmental entities, philanthropy, and by engaging communities and individuals as part of the solution. This workshop report includes the identification of a number of priorities for such a concerted, all-actor response to wildfire.

2. EXECUTIVE SUMMARY

We are experiencing new patterns of wildfire across western North America, breaking records for the size and severity of fires and the timing and length of the fire season. This changing fire regime is related to the frequency of droughts and extreme weather associated with a warming climate. We are also experiencing larger, catastrophic 'megafires' that are resulting in loss of life and property, while the cost of managing fires is escalating exponentially. Suburban development is expanding at the wildland urban interface (WUI) and fire and forest management agencies are trying to respond to these changes, seeking ways to make our wildlands and communities more fire resilient. At the same time, they are being asked to balance competing demands of fuels management, air quality, biodiversity conservation and carbon sequestration, all the while ensuring the safety of infrastructure and property.

Executive Summary

In 2019, with these challenges in mind, the Gordon and Betty Moore Foundation brought together a diverse group of experts and practitioners for a workshop to identify opportunities for improving the response to early fire. Based on the workshop recommendations, a number of projects were funded to help foster healthy fire-adapted ecosystems and develop resilient fire prone communities. Since that time a number of new state, federal and philanthropic initiatives have been launched to address aspects of the wildfire problem.

The Foundation convened a follow-up workshop in March 2022 to summarize project progress; identify potential connections between projects and in the context of the various new fire initiatives; and identify overarching priorities and gaps in the current activities. The broader community priorities that emerged from the workshop discussions are grouped in the following major themes around the need to:

1. Improve government, agency and philanthropy coordination and formulate a consensus long-term strategy and unified vision for how to address western wildfire, which reflects a deeper understanding of changing fire and climate regimes.
2. Set up an authoritative platform for knowledge and data sharing
3. Integrate various technologies to improve early fire interventions.
4. Develop a blueprint for landscape management and fuels treatments that yield ecosystem health and community resilience.
5. Create the trained workforce needed to implement the necessary interventions at scale.
6. Give greater attention to the impacts and costs of fire on human health, with an emphasis on air quality.
7. Better understand societal perceptions of fire and put in place effective policies that can help communities live with fire.

3. A SUMMARY OF GRANTEES' COLLECTIVE PROGRESS.

The 2019 workshop on fires immediate response systems focused on new technologies and the needs of the fire monitoring and management communities. Prompted by the occurrence of a number of megafires in California, exacerbated by drought and extreme weather, resulting in loss of life, property, and ecosystems and ecosystem services, the workshop explored gaps and priorities for action. The final report emphasized the need to strike a better balance between immediate response and pre-fire management. The major recommendations from that report are shown in Table 1.

Table 1: The Major Recommendations from the 2019 Immediate Response System Workshop Report (not in order of priority)

1. Develop a shared, **integrated platform** for diverse sources of data, intelligence and information.
2. Conduct new wildfire risk assessments with **high-resolution mapping** technologies.
3. Improve scientific understanding of "megafires" through **retrospective analysis.**
4. Enhance **fire behavior models** and associated inputs for real-time prediction (including an increase in micro-wind sensors in known high-risk areas and wind corridors).
5. Perform a **cost-benefit analysis** of investment in solutions vs. reactive management.
6. Target investments in the development and adoption of **new technologies**.
7. Expand **multi-stakeholder** dialogue, collaboration and action.

Building on these recommendations, the Foundation developed a strategy for its exploratory contribution to the 'early fire' phase (Fig. 1). The overarching goal of this early fire strategy is to neutralize the threat of catastrophic fire through improved and integrated early wildfire detection, assessment, and response, and a deeper understanding of megafires and changing fire regimes.

The Foundation has since built its portfolio of investments around a long-term vision of wildfire resilience in western North America, by fostering healthy, fire-adapted ecosystems and developing resilient fire-prone communities. The following core strategies are now supported to achieve these twin ecosystem-community outcomes:

1. Ecosystem pre-fire interventions.
2. Community pre-fire interventions.
3. Early-fire interventions.

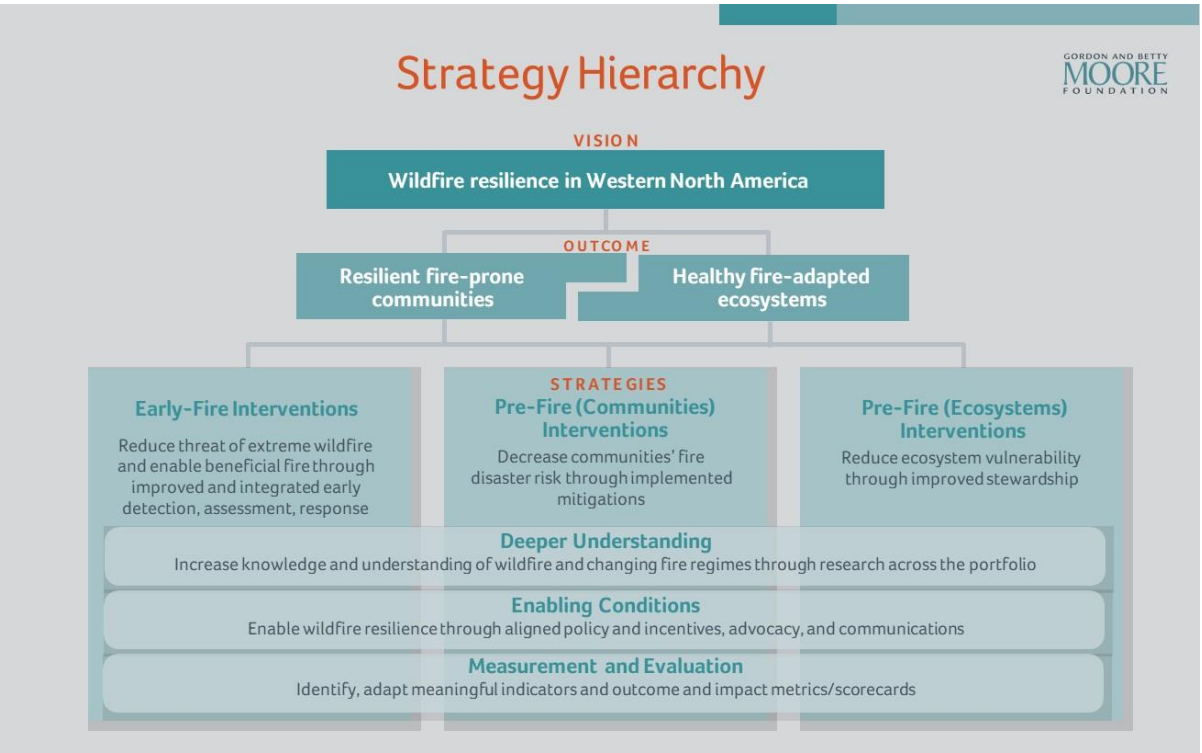

Figure 1. The strategy for wildfire resilience and the current areas of program emphasis.

An additional strategy of measurement and evaluation cuts across all four topics to enable adaptive management.

In response to these recommendations, more than 20 outcomes-based projects were funded addressing one or multiple topics to test different approaches or to assemble a mosaic of complementary solutions. The March 2022 follow-up workshop provided participants a forum to provide project updates, identify shared gaps and challenges, and make connections among their projects. In addition, attendees were asked to consider the broader landscape of fire research and development and identify priorities for an all-funder, all-actor agenda to achieve wildfire resilience.

Significant progress has been made in the 'early fire' and 'deeper understanding' work. Recent grantmaking has also supported pre-fire ecosystem and pre-fire communities' interventions, and measurement and evaluation.

3.1 DEEPER UNDERSTANDING.

A better understanding of catastrophic megafires is being addressed by a UC Davis, UC Berkeley, and EarthLab collaboration. Even in very large fires, a few individual spread-days account for most of the area burned and the risk posed by megafires. Focusing on drivers at a daily timescale may accordingly produce new insights about drivers of extreme behavior. Daily maps of fire spread and intensity have been developed for California from 2003 to 2020 and were used to help develop a quantitative definition of megafires, based on spread rate, maximum burning intensity, and total area burned. A summary of the location of megafires from 2003 to 2020 is shown in Figure 2. The project team is using machine learning to evaluate the contribution of multiple kinds of drivers to megafire development, including extreme weather, topography, fuel load and continuity, firefighting resource constraints, and location.

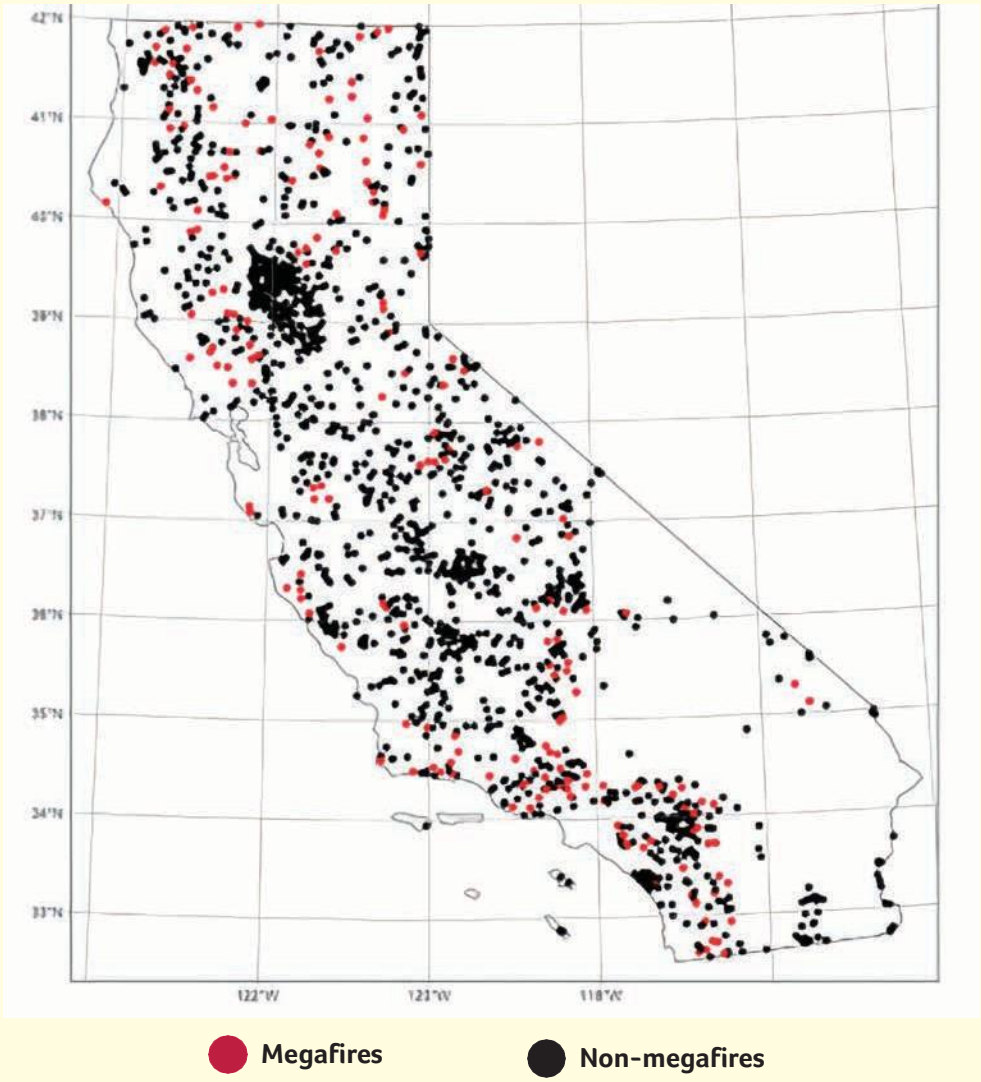

Figure 2. Megafires 2003 to 2020 (EarthLab).

An increase in our understanding of the complex and dynamic relationships among the interrelated management priorities of preserving life and property, maintaining forest health, and managing carbon storage is being formulated into a theory of change (EDF/FireSat). The theory will take into account changing wildfire patterns and address varied approaches to wildland fire management and obstacles to new systems uptake. A study was funded to develop a deeper understanding of the costs of wildfire and a report was developed by the California Council for Science and Technology which summarizes what we know (and don't know) currently about wildfire losses and costs across various sectors and presents a framework for better understanding the costs of fire in California. The report points to gaps in the current tracking of wildfire costs in the areas of mitigation and public health and identifies a need to account for natural resource values and ecosystem services and function.

Although the relationship between extreme weather events and the occurrence of recent megafires is recognized, there is insufficient understanding of how fire regimes will continue to respond as the climate changes. Two studies have been supported to deepen our understanding of future fire by developing possible scenarios using models that simulate the controlling processes, and could inform fuels and fire management strategies. The Cary Institute of Ecosystems Studies is developing western U.S. projections of fire for the 21st Century, using the latest downscaled climate models with a daily time-step. This study will evaluate whether and where current management approaches could decouple fire activity from climate and foster forest resilience. A Berkeley Lab study looks more closely at climate-driven changes in fire behavior for different forest, woodland and grassland ecosystems.

3.2 PRE-FIRE ECOSYSTEM INTERVENTIONS

The objective of this program area of emphasis is to reduce ecosystem vulnerability to fire through improved stewardship. It is understood that some of the forests of California are surviving by ecological inertia, as the climate conditions under which they developed have changed. These forests are at risk of catastrophic fire, which will facilitate their transition to a different vegetation composition. Referred to as "zombie forests," the Stanford Woods Institute is identifying and mapping the location of these forests (AP Hill, et al. In Review. "Low elevation conifers in California's Sierra Nevada are out of equilibrium with climate." Figure 3.) and to understand the future of these forest ecosystems under a changing fire regime.

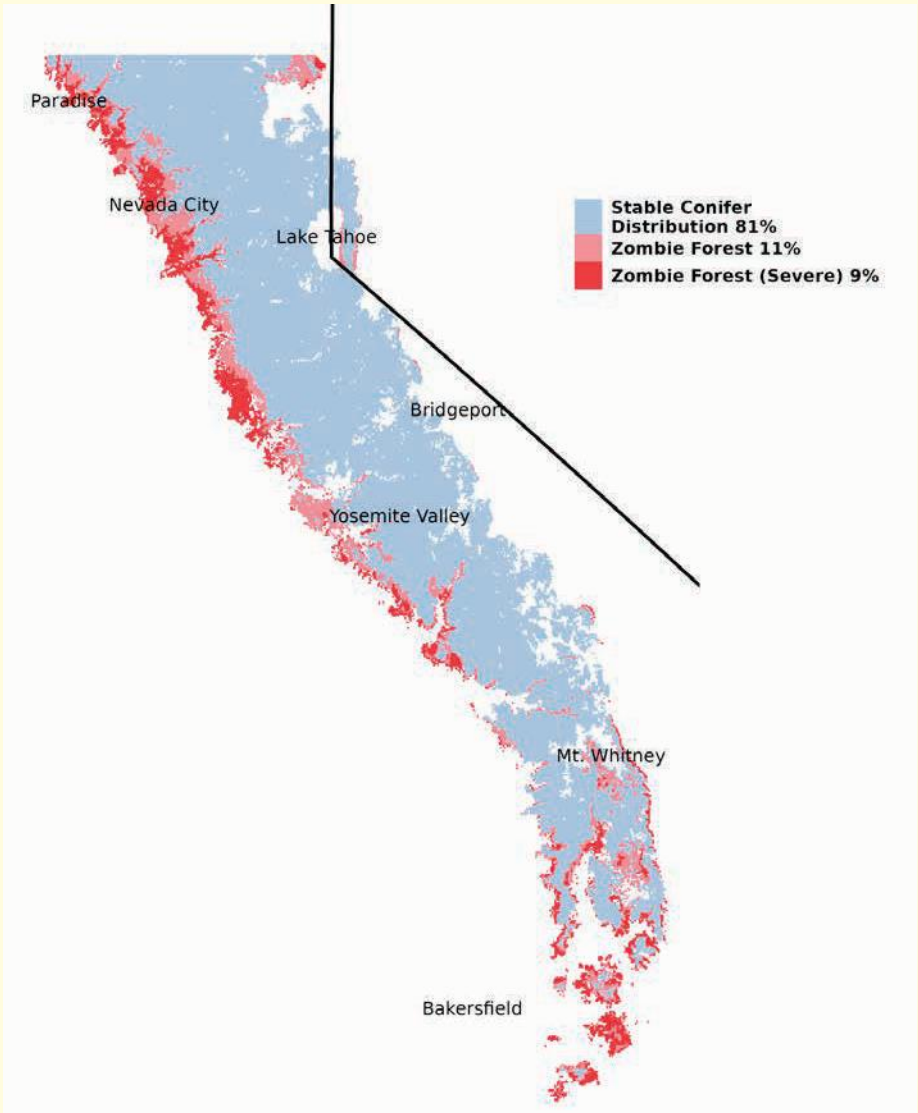

Figure 3. California Zombie Forest Distribution

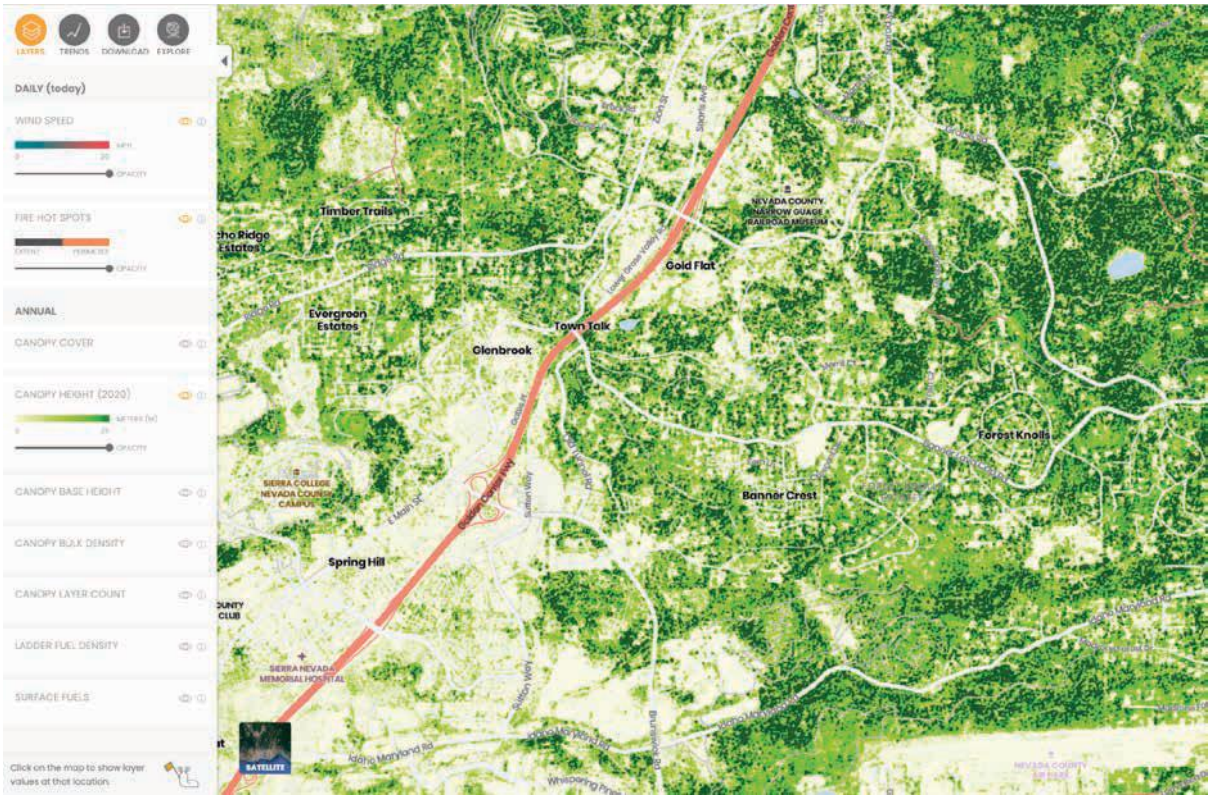

Figure 4. An example of maps generated by the California Forest Observatory (Salo Sciences)

Fuels management is the primary way to prepare ecosystems to be more resilient to fire. The California Forest Observatory has been funded to support risk assessment post-ignition, but also supports mitigation strategies by providing data and information on fuel load and high spatial resolution maps of fuels and fire hazards. Working with Planet, Salo Sciences has developed new statewide maps of forests and trees from very high-resolution satellite imagery across California, and the platform is now expanding to other regions globally.

The Nature Conservancy is leading an initiative on forest resilience in the Northern Sierra Nevada on forests not yet impacted by high intensity fires. Strategies for restoration are being developed and tested. Working with the Feather River Land Trust, a retrospective study on fuel treatment effectiveness is being developed for three fires that occurred in. A related activity with the Truckee Donner Land Trust is developing protocols for post-fire recovery and restoration.

3.3 PRE-FIRE COMMUNITIES INTERVENTION

The objective of this program area of emphasis is to decrease communities fire disaster risk through mitigation activities. Fires enter into communities primarily at the wildland urban interface (WUI) which is where mitigation efforts are being focused.

The American Planning Association defines the WUI as any developed area where conditions affecting the combustibility of both natural and cultivated vegetation, structures or infrastructure allow from the ignition and spread of fire through the combined fuel complex. According to The Community Wildfire Planning Center thirty-two percent of all housing units in California occur within the WUI. Decreasing communities' risk to fire requires an understanding of how fires spread and move through the built environment.

- A UC Berkeley study is being supported to understand ember exposure and to quantify structural ignition. This includes developing a better understanding of home-to-home fire spread and linking ember exposure to fire spread models.
- Pyrezo is funded to develop a ground-based wildfire risk tracking system focused on fire pathway mitigation and standardized mitigation measures.
- The Western Fire Chiefs Association is working with Interra to create a decision-support tool is being developed to capture data and share information on mitigation and resilience activities.
- Zonehaven is developing an innovative decision-support system which includes fire detection, fire spread and community notification has been developed and tested in multiple counties.
- Conservation X Labs will work with Indigenous communities, using an open-innovation approach to understand and share traditional knowledge and community perspectives on points of intervention, prevention and detection.

3.4 EARLY-FIRE INTERVENTION.

The objective of this program area of emphasis is to neutralize the threat of catastrophic fire through improved and integrated early warning detection, assessment and response, which together yield critical Decision Space. The 2019 workshop, identified a number of new technologies that might enable a quicker identification and response to fires.

UC Berkeley and Fireball developed FuegoMap, a system which integrates machine-learning based rapid fire identification with the 1200+ cameras of the Alert Wildfire system, satellite, and airborne detections (Figures 51, 5b).

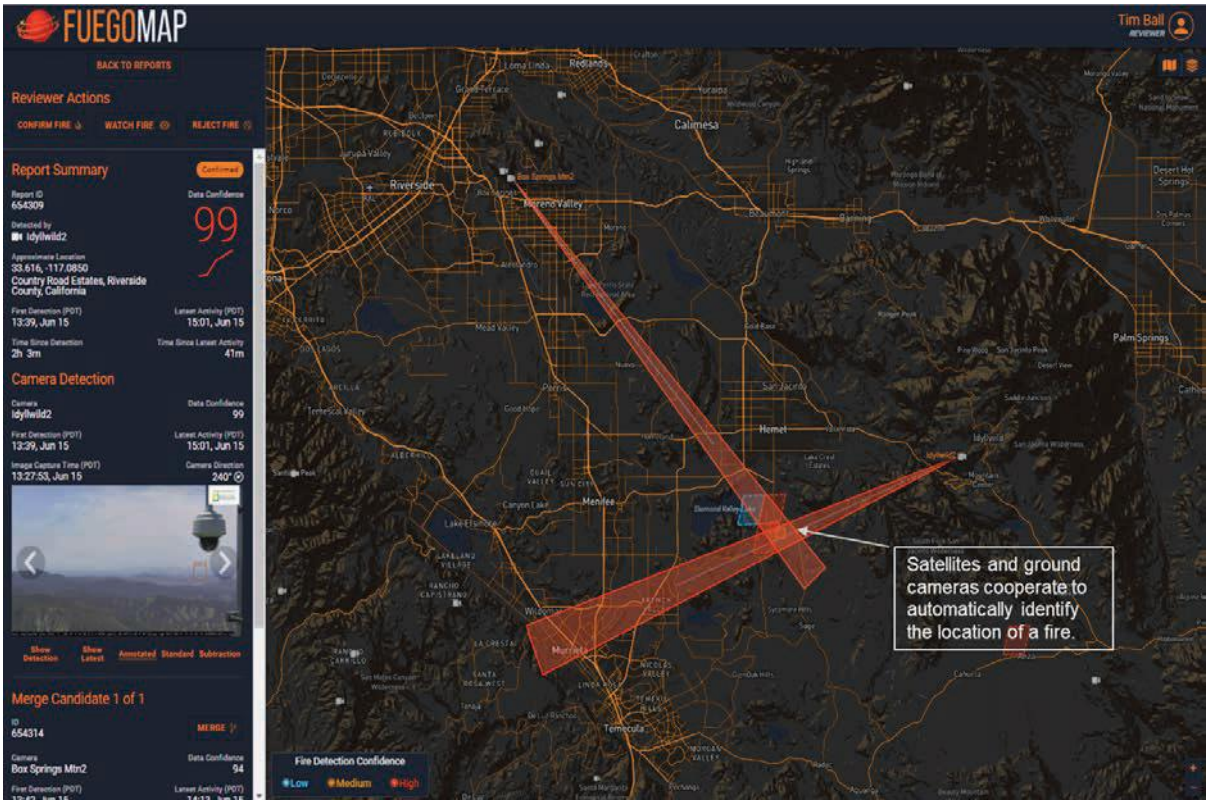

Figure 5a. Satellites and ground cameras cooperate to automatically identify the location of a fire. https://fuego.ssl.berkeley.edu/ (UC Berkeley/Fireball)

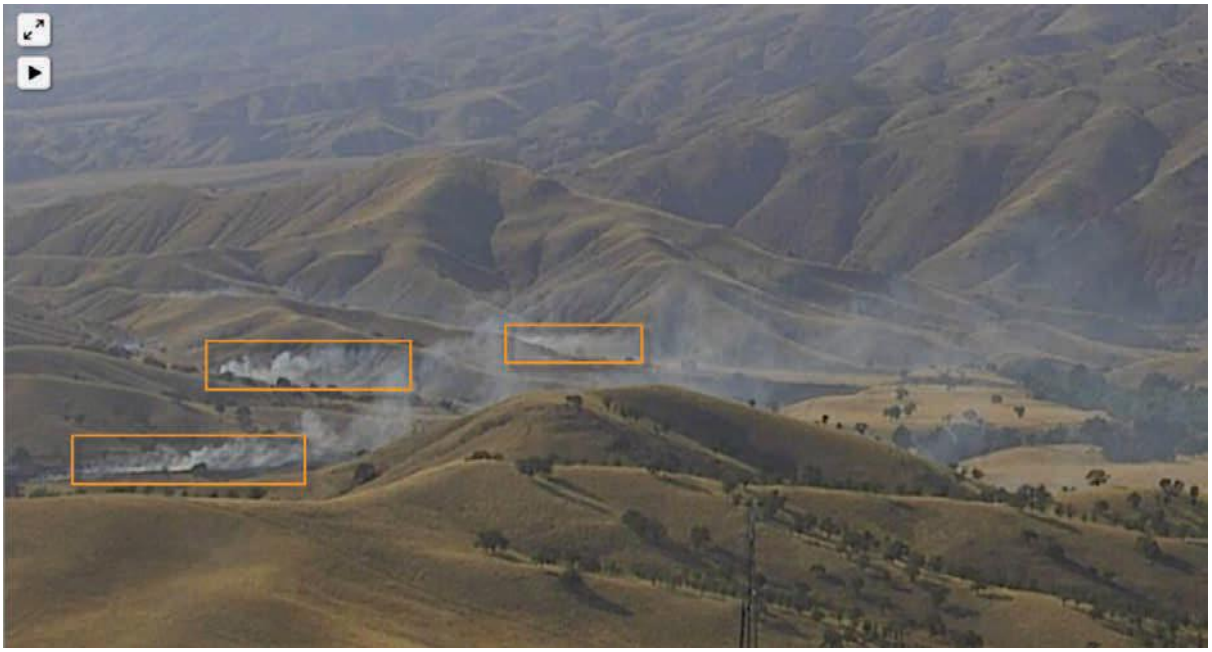

Figure 5b. At 3:02 PM on 11 July 2021 Fuego Map ground-based cameras automatically alerted Kern County Fire Dept. that they had not one, but three fires, along the railroad tracks near Bealville, Ca. (UC Berkeley/Fireball)

Figure 6. The Rain MK2 Aircraft being tested to rapidly contains wildfire ignitions in San Mateo County

Good Machine is developing high-altitude balloon platform providing continuous observations for early fire detection and alerts, and is being tested with a utility company to generate a sustainable business model that would provide early detection and private air response. Unmanned aerial systems (UAS) have been proposed as a low-cost means to provide fire identification. A wildfire containment system consisting of large UAS carrying fire retardant is being tested by Rain and the San Mateo County Department of Emergency Management to rapidly suppress wildfire ignitions in the earliest, incipient phase. The Rain MK2 aircraft being used in this project is shown in Figure 6.

A new approach to fire suppression in the WUI is being investigated through a series of lab and field trials applying liquid nitrogen. This project is exploring UAS capabilities for delivery and application (Northeastern University). Getting timely and usable information from different sources into the hands of fire managers is an important component of effective fire management. A FireScoreOps platform has been developed by Jupiter Intelligence to provide information on fuel condition, fire detections and fire behavior in support of fire management, with an emphasis on detection and suppression.

Two projects from UC Berkeley and Fireball are working to improve technologies for satellite fire detection. A concept for an enhanced geostationary fire monitoring system which would significantly increase the spatial resolution and the frequency of observations provided by current geostationary sensors is being developed (Figure 7a). The sensing system specifications indicate that this system could detect a fire of about one megawatt radiated power, or about 30 square meters (the size of a semi-truck trailer). Airborne data on fire energy fluxes needed to help design the associated detection system are being collected using a thermal camera system designed for fire detection (Figure 7b).

EDF FireSat is developing a concept for a constellation of low-earth orbit small satellites providing frequent very high-resolution imagery to assess fuel condition and detect fires. Both low-Earth orbit and geo-stationary satellite observations can make significant and complementary contributions to real-time mapping of fire-spread and intensity.

Figure 7a. The Field of View (white trapezoid) of the planned FUEGO Geo-synchronous fire-detection Satellite.

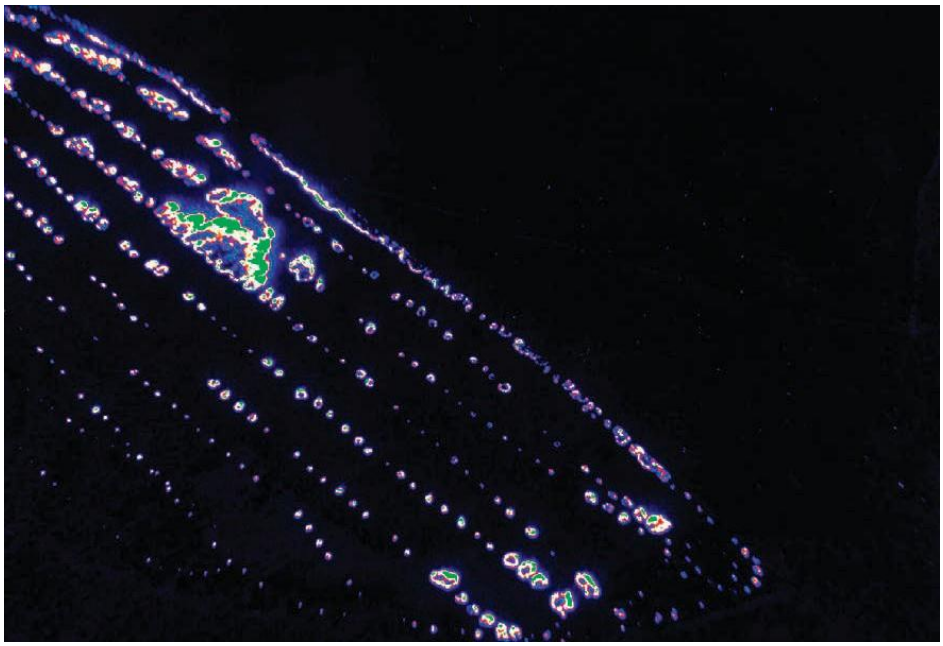

Figure 7b. An image of the radiation from a progressing prescribed fire that was compared to radiation measured by NOAA's GOES-East Geo-stationary satellite (UCB/Fireball).

Two projects are trying novel approaches to soliciting new ideas and technologies for early fire detection and response through open innovation challenges. XPRIZE Wildfire is working to apply their challenge approach to creating autonomous systems for the rapid, precise detection and suppression of dangerous wildfires before they become major fire events. The competition may also uncover early intervention solutions. The X-Lab has established course competitions connecting fire science and technology innovation at with the UC Berkeley Disaster Lab with students, faculty and scientists, participants in the FIRE Foundry program, and fire professionals, with a focus on particular gaps in fire services (including better prediction, forecasting, and real-time response) and field trials at Camp Roberts.

3.5 ENABLING CONDITIONS, MEASUREMENT AND EVALUATION

In addition to identifying potential technical advances and improved methods for fire management, the 2019 report recognized the need to help inform and advance policy formulation at different levels.

At the federal level, the Federation of American Scientists is being funded to provide Impact Fellows to support wildfire initiatives at the Office of Science Technology for the President (OSTP) and the USDA Department of Natural Resources and Economics (NRE). They are also developing a strategic policy portfolio that targets prevention of costly wildfires, better management of wildfires that do occur, reduction in costs and losses, and increased community and ecosystem resilience to wildfire.

The Aspen Institute is developing a Wildfire Resilience Policy Roadmap to guide policy and decision makers on interventions and actions, with a plan to convene a Wildfire Summit in the Fall of 2022. The California Council on Science and Technology gave a number of briefings at the state level on the findings of their study on the Cost of Wildfire in California, which were well-received.

Two additional projects are being implemented to quantify community resilience to fire, The Aspen Institute is defining key interventions from various stakeholders and develop a resilience roadmap for communities and Berkeley Law is developing metrics of resilience, including socio-economic and community concepts.

In summary the above projects and activities supported by the Moore Foundation at various stages of implementation, are aimed at informing policy and action including:

- Improving our scientific understanding of recent fire history, and current and future conditions.
- Developing new data and maps to support early fire interventions.
- Developing technologies and approaches to provide information for decision support, increase community and ecosystem resilience, suppress fires, mitigate fire impacts, prevent loss of life and property and provide integration of disparate data and information.

In the process of implementation, grantees are engaging closely with different stakeholders and communities to understand their needs and what they currently use to inform decisions. A two-way exchange of understanding, knowledge and lessons learned is an essential component of effective decision support. Co-development of decision support tools has been proven as a necessary and effective approach. Given the very large budgetary implications for fire management and impacts, cost benefit analysis is increasingly part of any proposed intervention.


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4. GAPS AND CHALLENGES

Although a number of the 2019 workshop recommendations are being addressed and multiple projects are now underway, gaps remain. The March 2022 workshop provided an opportunity for project participants to come together to identify shared challenges and opportunities. Breakout sessions allowed participants to look for opportunities to link between projects to help overcome the challenges. The breakout groups were organized under the five strategies depicted in Figure 1.

In the area of Deeper Understanding the challenge of quantifying and managing transient vegetation due to changing climate and fire regimes was identified, along with the need to better understand the complex interrelationships among water, climate and fire. Social and ecological uncertainties were discussed including: the role of the forest extractive industry in mediating fires; the process and drivers of urban expansion at the WUI; and the associated perceptions of fire risk in communities. Critical missing data result in insufficient information (e.g., about location and extent of prescribed burning and post fire recovery, and location and characteristics of buildings, fuels, and infrastructure in the WUI to help model and understand potential for fire spread). Similarly, a better characterization is needed of the varying spatial and temporal footprints of fire impacts that can extend well beyond the fire flame perimeter, including watershed impacts, evacuation perimeters, utility disruptions, and air quality impacts from smoke. Some topics remain poorly understood, such as the legal limitations on fire-fighting that influence priorities and constrain the overall response.

In the area of Pre-Fire Ecosystem Interventions the overall lack of capacity for local operators to implement new research-informed action and the insufficient number of trained and registered foresters and prescribed and cultural burn practitioners for the amount of work needed, were seen as major challenges. In addition, the lack of capacity and infrastructure (timber operators, sawmills, etc.) for biomass/fuel that is removed merits attention and solutions for broader scale implementation. The overall capacity constraints mean that there is a need for careful prioritization of fuel reduction efforts to have the greatest benefit in terms of communities, habitats and forest climate resilience.

Outdated regulatory and permitting frameworks present an obstacle to changing needs for expanded fuel treatments and prescribed burning. Translating research findings into prioritized on-the-ground action at the local level, along with the associated need for building long-term relationships between researchers and on the ground implementers remains a challenge. Overall, the group recognized a need for a major change in the forest management agency to enable an effective response to changing climate and fire, allowing greater agility to plan and implement projects efficiently and at scale and try new management approaches. There is a need for Increased emphasis on management activities that enhance forest resilience.

In the area of Pre-Fire Community Interventions one of the major gaps identified was our understanding of how fire moves through structures and communities in the built environment at the WUI. There is a need for a better understanding of ember density and home-to-home transmission under different fire conditions. Data from previous well-documented fires and ground-based information on building structures might help to identify factors that impact fire spread through the WUI.

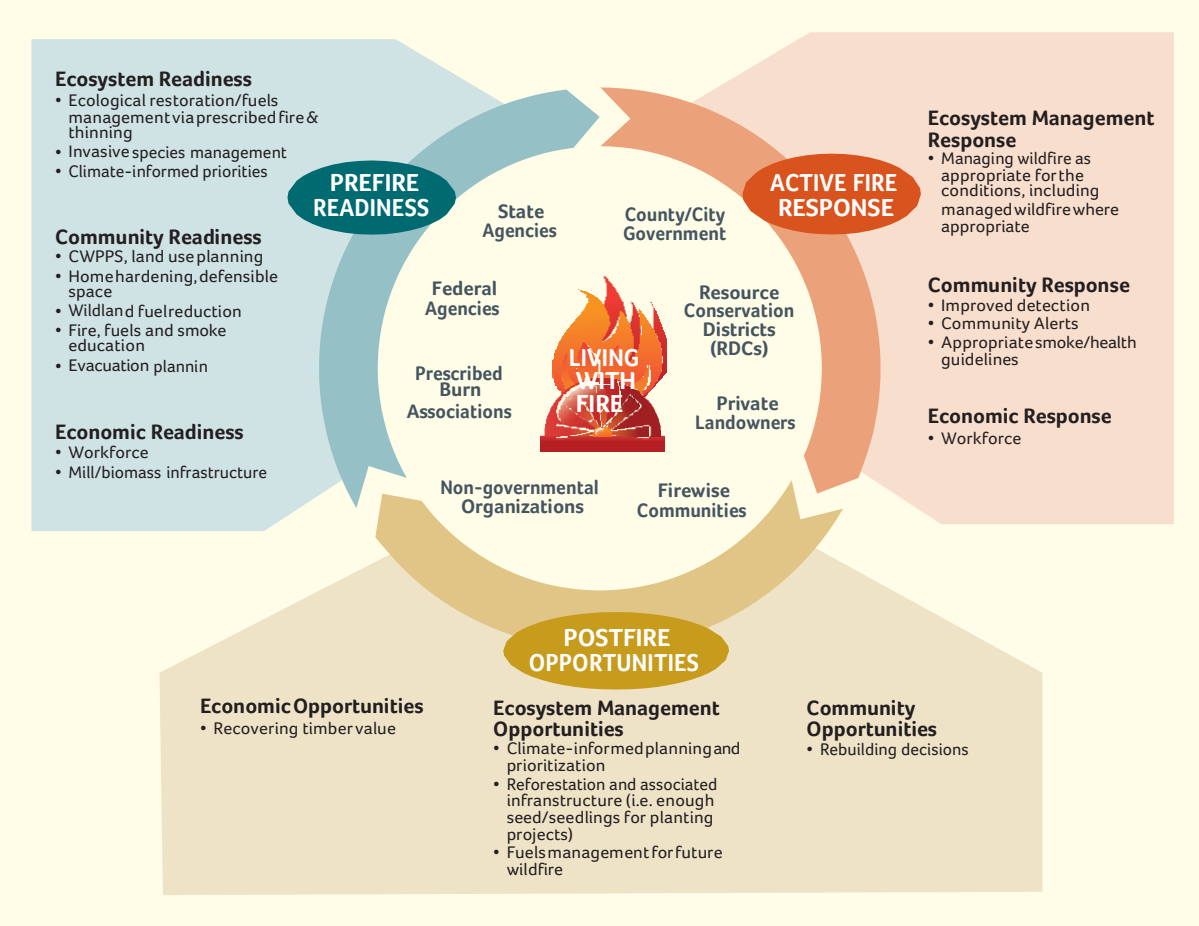

Figure 8. The readiness, response and post-fire opportunity cycle when living with fire (The Nature Conservancy).

There is a lack of funding to enable pre-fire planning in poorer counties. The existing static maps lack sufficient detail and current status, to enable effective local pre-fire planning and up-to-date risk maps could also help inform forest health planning at the federal level. Parcel-level risk maps could be used as a base-layer for mapping the location of at-risk populations. It was noted that although satellite data have proven to be useful for ecosystem mapping, their utility at capturing the information that is needed in terms of the WUI and defensible spaces has yet to be proven. The increased availability of very high-resolution satellite data provides an opportunity to explore these information needs and when combined with ground survey data, could start to provide improved fire risk information at the parcel scale.

There was discussion on how to give communities the agency to make themselves safer, specifically around home hardening and fuel mitigation. There is a need to help residents understand the pre-fire environment and take responsibility for increasing resilience. A balance is needed between education and enforcement, with strong political support for enforcement. The Zonehaven “know your zone

campaign" has proved to be an effective way to engage communities. It was also recognized that policies need to be aligned to support positive outcomes and that ambiguity on what to do leads to no-action. The insurance industry has a key role to play in encouraging individual action. The concept of a LEED-type rating for fire in the WUI (layout, fire-hardened buildings, etc.) tempered by local environmental conditions was suggested.

In the area of Early-Fire Interventions, the challenge of making the tools being developed more accessible and useful for incident command/responder was identified. Targeted training of new firefighters on new technology will increase adoption and will build future fire-service leaders that understand the technology. Technology demonstrations with agencies will help with outreach and provide an opportunity for different projects to meet with the firefighter community. It was recognized that there is a benefit in undertaking technology transfer at the local level where there is often a lack of access to the latest technology and with agencies that have the benefit of local knowledge, enabling a faster fire response. It was also recognized that different procedures or disagreements between federal, state and local agencies can slow response.

In the area of Measurement and Evaluation, a trusted integrated platform for vetting and sharing data is a major gap and data remain fragmented, widely distributed and some critical data sets are missing. Participants raised questions concerning the long-term institutional responsibility for such a system

Figure 9. Summary of issues related to fire at the WUI.

and mechanisms for community participation in such a platform. Government ownership of such an integrated platform was deemed necessary. Economic benefit is an important metric in the policy arena but not the only one. There is a need to establish the cost of financing mitigation actions at the scale needed to make a significant impact. In this context, there is a need to connect treatments and other mitigation actions to a quantified reduction in risk and potential damage (including downstream effects like health and ecosystem services) to motivate policy making and financing. Quantifying the human health impacts of fire was identified as a major measurement gap. Major gaps identified by the breakout groups are shown in Table 2, on the next page.

From the first breakout groups and plenary discussions on gaps and challenges, several common themes emerged across the different focus areas. There is an overwhelming desire to convert ideas into beneficial action and to prioritize the areas for action. For each of the proposed solutions there is a need for measurable impact. The sequence of first developing the scientific understanding to help inform policy implementation, followed by community engagement was recognized. The issue of how and when enforcement is needed was also raised.

Technology transfer activities benefit from co-development (involving the intended end-users of tools/products from the outset) but places an additional burden on the willing operational users. It was recognized that on-the-ground operators (fire, forest managers) already have numerous competing demands on their time and the same can be said for the policy makers and agency managers whose involvement is critical for needed implementation. This means that there are real limitations to scaling up current systems (including the workforce), to address the extent and magnitude of the wildfire problem. Operational agencies can also be limited in terms of their appetite and ability to test new things, as at the end of the day they need to deliver on their operational mandate.

With the overall increase in interest and funding for wildfire, there are a growing number of activities and people involved. One of the challenges is knowing who is doing what and establishing workable mechanisms for coordination between the various programs and activities at the federal, state and local level. The need for a clearinghouse for information on various activities was a common theme.

It was noted that the Foundation's current focus on Pre and Early Fire stages and upstream solutions does not extend to Mature- or Post-Fire issues, including disaster relief or recovery.

Table 2. Examples of Major Gaps Identified

- **Capture capacity.** Improved capacity to capture and use fine-grained data and insights. For example, develop up-to-date parcel-level fire risk maps; sub-daily fire spread maps; Integrating ground-based data into landscape level fuel models; comprehensive and up-to-date county level lidar data to assess defensible space in the WUI.
- **Data integration.** Establish and sustain an authoritative Integrated Data Platform for fire related data and information from all available data sources for western fires, including bringing together and harmonizing fire detections from multiple satellite assets for the Western States, including international and commercial sector satellite assets .
- **End-user requirements.** Agreement on end-user requirements for detection/monitoring payloads. Separate efforts are underway and could benefit from increased communication or even convergence around well-specified requirements.
- **Clearinghouse.** Establish a knowledge clearinghouse of projects on western wildfire, including locations, results and lessons learned and points of contact.
- **Deeper understanding.** Support for hindcasting and forecasting to improve resilience, catastrophic fire prevention and mitigation: forecasts of effect of climate change on extreme fire behavior; attribution of cause of increases in fire extent and severity; approaches to model human settlement patterns; and decision-making in response to future fire.
- **Satellite-based observational products.** Need to strengthen pre-fire planning to adapt to changing fire regimes, with updated observations of forest ecosystem structure, fuel mass, moisture inc. for model evaluation.
- **Quantification.** Quantify the ecological benefits and avoided losses from improved fire stewardship, and facilitate accurate accounting of the full costs of fire from disrupted ecological services and human communities, so that the costs of actions needed to increase wildfire resilience can be compared against inaction.
- **Regulatory frameworks.** Eliminate regulatory barriers to improved wildfire management (e.g., update permitting procedures to expedite fuels management); adapt UAV policies to facilitate use of high-payload UAVs (drones) for expedient aerial delivery of suppressants; facilitate consistent state and/or federal approaches (e.g., to evacuation management).

Photos courtesy of Insurance Institute
for Business & Home Safety

5. OVERARCHING PRIORITIES FOR IMPROVING WILDFIRE RESILIENCE.

We have entered a new paradigm for western wildfire that will require more than business-as-usual in terms of our response. The needs for protection of life and property, maintaining environmental quality, ecosystem management, carbon management, and biodiversity conservation come together in the context of the various activities associated with fire and fuels management at all stages of Pre-Fire, Fire Immediate Response and Post-Fire Recovery (Figure 9). It should be noted that although the considerations appear to be competing there are some synergies in terms of the management response to the different competing needs.

The relationships between these competing needs are dynamic both in time and space, due to the impact of climate change and the associated extreme weather, changing snowpack, persistent drought and the continued expansion of housing and infrastructure at the wildland urban interface. This dynamic situation requires that agility and flexibility be built into the approaches to management and response, and for systems to be designed long-term sustainably.

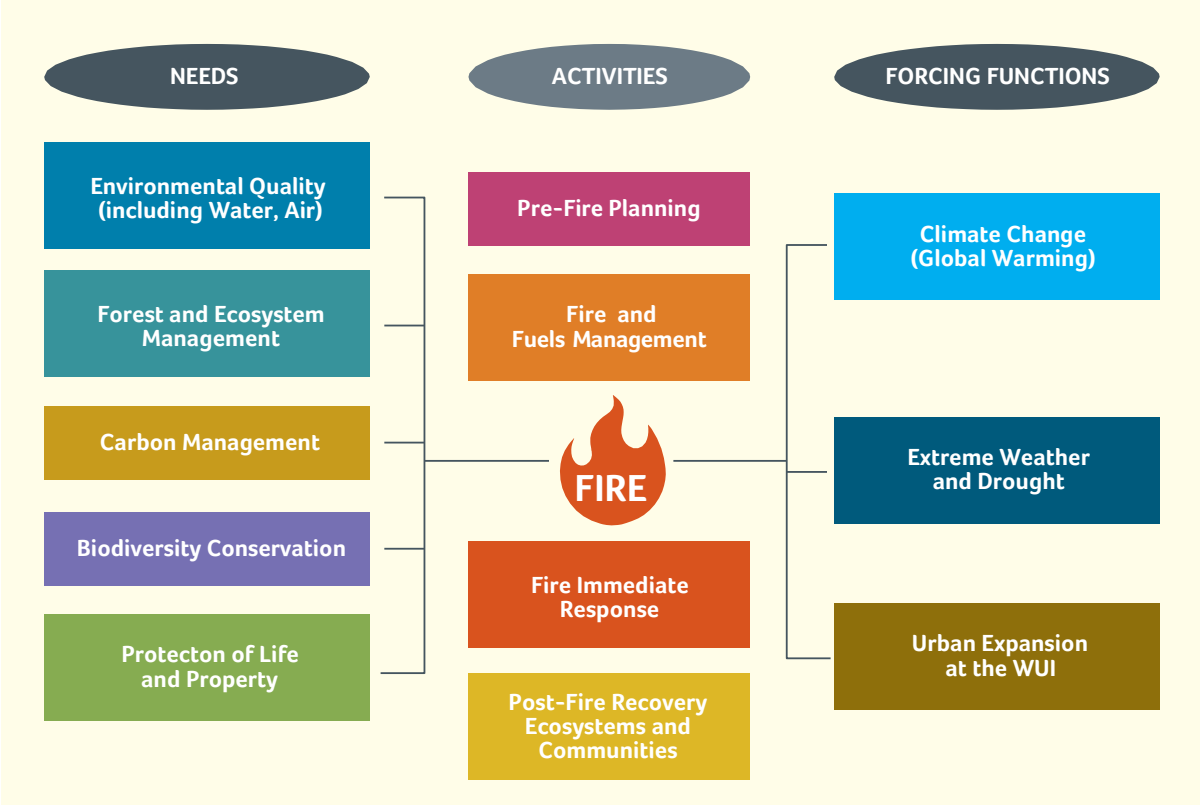

Figure 10. Needs, activities and forcing functions associated with Wildfire Resilience.

Western North America has always been fire-prone, and wildfires will always be with us, but extreme fires are now expected to become more frequent, more extensive, and more severe. Pre, early, mature, and post-fire phases are cyclical and interlinked. In this context we need to be planning for the next fire, and for still larger fires that will follow in the coming decades, including fire emergencies, while also increasing beneficial fire and learning to coexist with it. The cyclical nature of pre-fire readiness, fire response and post fire opportunities associated with living with fire are shown in Figure 10. The post-fire to pre-fire pathway in the cycle (e.g., decisions about rebuilding, or postfire land management) is critical but is often overlooked.

Following a number of record fire years and catastrophic fires events, a number of new major initiatives focused on western fire are being established at the federal and state level with significant public funding, for example: the Bipartisan Infrastructure Framework, California Wildfire & Forest Resilience Expenditure Plan, and the NASA Western Wildfire Initiative. There is also increasing interest from philanthropic organizations to fund wildfire activities, with a desire and a recognized need for collaboration. This collaboration can be effective and guard against unnecessarily adding further complexity to this challenge (WTFG 2022). Non-government organizations at the national and local level are expanding their wildfire related activities and organizing around wildfire,[1,2] (Miller and Mach 2021). Professional organizations such as the International Association of Wildfire,[3] the GOFC-GOLD program[4] are providing a forum for fire science, monitoring, and management and providing position papers.

In the context of this broader landscape of increasing interest and activity, the workshop participants were invited to join breakout groups to identify and discuss their top three priorities for an 'all-funder, all-actor agenda on wildfire resilience'. The priorities that emerged from those breakouts group discussions are grouped under the following major themes:

- Government, agency and philanthropy coordination.
- Data infrastructure and knowledge sharing.
- Fire immediate response.
- Forest resilience and fuels treatments.
- Workforce development and human capital.
- Fire impacts on human health.
- Society, perceptions and policies.

The priorities raised in the breakout groups reflect the opinions and perspectives of the workshop attendees and as Moore Foundation grantees, their emphasis is on developing upstream solutions to the pre-fire challenges rather than on post-fire response and recovery.

1 https://static1.squarespace.com/static/545a90ede4b026480c02c5c7/t/61dcc1ca295def04119d88c3/1641857483133/Roles+of+NGOs+in+wildfire+relief+and+recovery_RB_2021.pdf

2 https://www.onepercentfortheplanet.org/stories/nonprofits-supporting-wildfire-aid-and-long-termsolutions

3 https://fireandclimateconference.com/wp-content/uploads/2022/02/IAWF-Position-statement-onclimate-change-Updated-Final.pdf

4 https://gofcgold.umd.edu/gofcgold-fire-implementation-team

5.1 GOVERNMENT, AGENCY, AND PHILANTHROPY COORDINATION

While each of the new federal, state and philanthropic initiatives around fire are useful in their own right, we still lack a shared vision and an overarching strategy for Western Wildfire Resilience with an associated implementation plan for coordination; as such these activities remain fragmented.

A high priority is to develop an overarching strategy for Wildfire Resilience and an all-of-government framework to implement it, encouraging and strengthening collaborative efforts across agencies and organizations, transcending institutional barriers and jurisdictions, overcoming competition between agencies and institutions for resources and supporting internal champions for positive change.

A well-coordinated, concerted effort towards common agreed-upon outcomes is needed—building consensus on the desired outcomes, and innovative strategies to achieve them, will require broad consultation of diverse stakeholder communities, a common lexicon and inevitably some compromise. Developing policies that require the involvement of multiple agencies provides an additional coordination mechanism. To establish and sustain such a concerted effort over the long-term, a bipartisan approach is needed to coordinate resources and activities across federal and state agencies. Further collaboration between government agencies is needed to address new and emerging, multi-partner issues, such as air quality and fire at the wildland-urban interface. Coordinated research centers, implementation plans, and partnerships with industry and local governments could help motivate action from the federal level down to local jurisdictions.

Wildfire may benefit from models applied to other natural hazards that have benefitted from cross-agency coordination, cross-cutting research and response amongst sectors. Government agencies will need to become more agile to adopt and implement new ideas and approaches and new resources will be needed to transition technologies and methods from research to operations for example by demonstrating approaches developed in the research domain as proven operational prototypes.

Philanthropy has the advantage of being flexible and agile in implementation and can support new, unconventional, or riskier approaches. It can also bring together actors from across disciplines and communities of practice who would not normally meet, to share experience, discuss needs and develop potential solutions. Coordination among philanthropy groups can help address immediate priorities to complement federal and state initiatives or pool resources to address some of the bigger resource challenges. For those interventions that prove to be useful and effective, there is a need for pathways between philanthropic funding and more longer-term federal or state program funding, which for example includes the long-term care and feeding of relevant data sets.

5.2 DATA INITIATIVE, DATA INFRASTRUCTURE AND KNOWLEDGE CLEARINGHOUSE

A key priority is to get the necessary data and information into the hands of those who are making decisions across the spectrum of wildfire resilience actors. Several diverse types and sources of data and information useful for decision-making are currently available from different agencies, universities and companies and new data are coming on-line. Efforts to combine and deliver these data are currently fragmented and uncoordinated. Some of the existing data sets are out-of-date and a few data sets needed to inform management decisions and advance models are currently missing (see Section 4). Research is needed to evaluate which data sets are the most useful or best for various applications, and if major data gaps exist; having multiple kinds of data more readily available would facilitate this kind of research.

A major new data initiative is a high priority, to bring together the data sets that are needed into a common platform and put in place the systems to routinely generate up-to-date data and information.

This initiative should provide metadata guidelines or interoperability standards and include an authoritative platform, where the data are collected, integrated, distributed and archived. The data should be vetted and their accuracy characterized with guidelines for appropriate use. The platform should target and be tailored to meet the needs of different actors and stakeholders (e.g., planners, fire and forest managers, fire responders and community evacuation services) through co-development of information products for decision support (Figure 10). The platform needs:

- An operational, institutional commitment and, ideally, to be government led.
- An innovative research and development element, exploring creative ways for advancing data and information delivery, for example through social media.
- A long-term commitment and data stewardship. This builds on a recommendation that emerged in the 2019 workshop (see Table 1.).

In addition to data, maps and surveys, there is also a need for a knowledge clearinghouse providing a database of current projects, their objectives, location (interactive maps), project partners and points of contact. This could be especially useful for pre- and post-fire analysis (tracking areas of prescribed burns, inclusive impacts from fires, displaying Calfire's DINS data, etc.). The knowledge clearinghouse would bring together the lessons learned and best practices from the various projects and activities of different groups and from different geographies on fire and fuels management and the experiences from the different communities of practice.

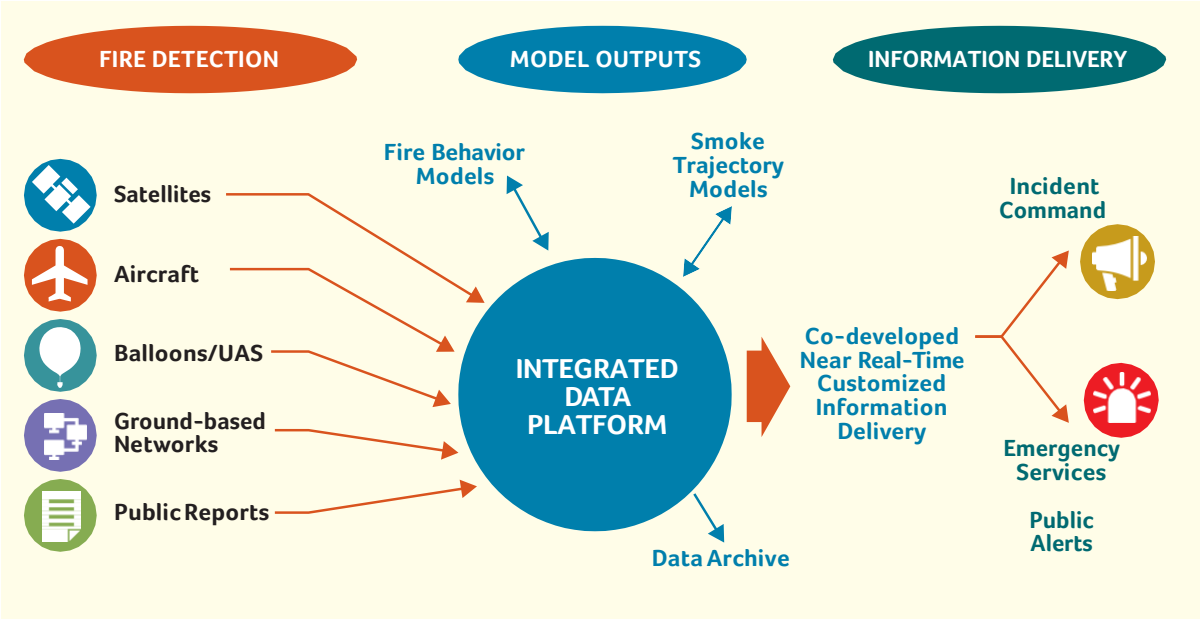

Figure 11. Data Integration for Early Fire Detection and Intervention.

5.3 INFORMATION TO SUPPORT FIRE IMMEDIATE RESPONSE

Getting useful information on current fire location, behavior, accessibility and the available assets into the hands of incident command and first responders before arriving at the fire is an important goal. If fires are going to reach extreme spread rates, they often do within the first few days after ignition. The development and uptake of such decision support tools that provide the necessary information at the right time and that are easy to use remains a high priority. Web-based geographic information systems play an important role in combining and integrating spatial and point data from multiple sources for both analysis and visualization.

Early detection of a fire, and a characterization of its size and trajectory can help inform decisions. A comprehensive assessment of the various requirements for fire detection and alerts from decision makers and early responders at the federal, state, county and local management levels, including incident command is needed. The assessment should include such issues as required detection accuracy, locational accuracy, frequency, reliability (e.g., smoke and cloud obscuration), latency and form of data representation and delivery. Several efforts are attempting to do this, but a comprehensive assessment has yet to be made. In some cases, establishing the requirements will require additional co-developed research. Once established, these requirements would benefit from a broad review.

With the requirements well-understood, they can be mapped to current capabilities (satellite, aircraft, ground networks for fire detections and fire behavior model outputs) with an assessment of reliability, geographic extent and longevity, to see which of the requirements can be met.

A comprehensive assessment of what is currently available and (ideal) end-user requirements provides the basis for enhancement or for new capabilities to be added to fill the gaps in early fire detection and monitoring and fire behavior modeling in support of fire early response.

As the user community for this information grows, a periodic revisiting of the requirements will be needed.

Satellite data are currently used for fire and fuels management and new sensing systems from NASA, NOAA and other space agencies are providing new capabilities. Commercial, very high spatial resolution satellite data are being used to augment ground surveys for mapping fire risk and post fire damage assessment and to assess the accuracy of coarser spatial products. A number of new fire detection and characterization systems are being proposed by both the public and private sector, but these efforts are often competitive. Airborne and balloon sensors offering new capabilities are also being tested.

Current efforts are often competitive and remain fragmented. A coordination initiative across both public and private sectors could review, evaluate, and operationalize the best available comprehensive remote sensing program (data and technologies) for western fire and fuels applications.

Ground-based sensing systems (fuel moisture/humidity, fire detection, wind speed, air quality) provide in-situ measurements and useful local information, which can be used alone or combined with other spatial data or integrated into models. In-situ measurements play an important role in model parameterization and validation. They could help fill one of the major gaps in environmental data for fire behavior modeling: accurate, fine-scale wind speed and direction data. To-date, the deployment of such ground-based networks and their integration with other data sources has been limited and an assessment of how they could be expanded and optimized is needed.

5.4 FOREST RESILIENCE AND FUELS TREATMENT

How to manage western forests under a changing climate and changing fire regimes is an ongoing and evolving challenge, particularly as forest management needs to encompass and balance the primary needs of protecting life and property, conserving biodiversity, ecosystems, and ecosystem services, and carbon management.

The science of forest resilience will necessarily continue to evolve with rapidly changing fire and climate regimes, but a fast-track study could bring together a blue-ribbon group of scientists and land managers to develop a five-year blueprint for western forest and lands management, based on our current understanding.

Recognizing that our understanding of forest resilience is still developing, the study should identify major unknowns and the priority science questions that need to be addressed. This can help guide science agency implementation.

Fuel treatment will clearly need to be part of any strategy for wildfire resilience; however a clearer understanding is needed of the scale at which this needs to happen to have a significant impact. Given the competing needs and limited resources in the forest management agencies, a spatially explicit and

prioritized plan for fuel treatment across federal, state and private lands is needed. The plan should be based on a consensus with an "all-of-government" plan for implementation.

Prescribed fires are an integral part of fuels management but come with a number of well-recognized challenges and risks. While safety and protection of life and property are of the utmost importance, the obstacles to implementing prescribed burns at scale need to be removed and the associated negative public perceptions managed. Engaging and empowering the public, including private landowners, tribes, and others, to take more control of burning on their lands, could be a major part of this effort to expand prescribed fire use and improve its public acceptance.

Similarly, some fires that do not threaten life or property could be monitored and left to burn under the right conditions, creating a patchwork of burned and recovering ecosystems, with the benefit of preventing catastrophic megafires. This will require a new choice-architecture that enables these decisions to be made more easily, while addressing safety and air quality concerns across the potential air-shed (See 5.5) and working with local communities to be part of the broader fuel management solution.

5.5. WORKFORCE DEVELOPMENT AND HUMAN CAPITAL

There are currently insufficient "boots on the ground" and other gaps in workforce and capacity to meet the needs for the necessary collective response to wildfire resilience. This shortage is in all sectors, including fire management and response, forest and fuel management, community resilience and building hardening, and wildfire tech innovation. It is also at all scales, including local, county and state. It is worth noting that a shortage is also apparent in the federal and state agencies, as they try to gear up to develop and manage new and, in some cases, large programs and initiatives.

A new initiative is needed to develop the workforce needed to address the changing wildfire paradigm across the western states.

There is also a need to: examine pay scales that will attract people into the workforce; put in place new extension and certification programs; and promote the necessary education and training programs for example in community colleges, to develop a pipeline of trained individuals familiar with the new technologies. In addition to current limitations in the workforce, attention needs to be given to the limited availability of heavy equipment for field management.

5.6 FIRE, SMOKE AND HUMAN HEALTH

Through a policy lens, insufficient attention has been paid to the health impacts of wildfire smoke, particularly with respect to vulnerable populations and environmental justice considerations. While we focus resources to mitigate the risk of property loss, we do not for smoke exposure (even though we know injury and death can result, particularly from smoke generated from severe fires). Better mapping and accounting for the full footprint of a fire should inform policy decisions.

We need foundational work on mapping "fire footprints," with a public health dimension that aligns with the "fire-shed approach" to management that is currently being implemented.

There is a need for a more nuanced messaging to the public and institutions on how best to cope with smoke events of different intensities. A better linkage is needed between the smoke plume and trajectory modeling community, satellite data providers, ground-based air quality measurement networks and the public health community to co-develop decision-support systems for forecasting, early warning and alert systems.

5.7 SOCIETY, PERCEPTIONS AND POLICY

Perhaps the biggest challenge is to bring about a necessary change in human behavior and perceptions about fire.

There is a need for greater public engagement in 'learning to live with fire' in our communities, involving landowners, homeowners, communities and fire fighters.

The concept of "good fire" needs to be understood and individual and collective responsibilities of community fuel management and property hardening need to be communicated, along with the inevitability of wildfire. The cost of action and inaction need to be established and presented in ways that people can understand, even at a personal level. The important role of prescribed fires and the effects of the associated smoke need greater public understanding. The idea of letting some safe fires burn rather than suppressing every fire needs greater adoption and public support.

Policies implemented for societal common good may not always be popular with individuals and those policies need particular attention. For policies to be effective, they may need to be enforced. Communicating and explaining policies in ways that people can embrace and that foster compliance is preferable to enforcement. There is a role for the behavioral and social sciences in establishing the best practices for communicating information, successful policy implementation and co-development of community solutions to effect positive change.

6. CONCLUSIONS

The societal challenges resulting from changing fire and climate regimes in western North America will continue, with a clear need for federal, state, and local government and the communities involved to come together to figure out how to overcome them–and in the process, establish more resilient communities and healthier ecosystems. To do so, we need a better understanding of the future to design systems that will meet the scale of the coming wildfire challenge, not just what we face today. New approaches are being tested and new technologies are enhancing current wildfire management practices. Good progress is being made by projects funded by the Moore Foundation to address some of the challenges associated with the pre and early fire phases and this workshop identified some important gaps and challenges.

Seven overarching priorities for action were identified. Above all, there is a need for a consensus strategy and unified vision on how to establish resilient fire-prone communities and healthy fire-adapted ecosystems, through all stages of fire. This is reflective of the Wildland Fire Leadership Council's Cohesive Strategy, with its goals for resilient landscapes, fire-adapted communities, and safe and effective wildfire response.

Participants were concerned that implementation of the Cohesive Strategy and meaningful progress toward its goals will be hampered by workforce and staffing challenges. A consensus strategy will need to address these challenges and the other gaps and priorities identified. It will also need to be developed with a strong scientific underpinning, a clear and measurable outcome with nested indicators to track progress over time, and broad consultation and buy-in from government (fire and forest management agencies, land use planners), private enterprise, and the various on-the-ground practitioners and stakeholders including tribes, non-government organizations, the business community, community organizations and the general public.

The strategy needs to account for the competing priorities of fire and fuels management to safeguard life and property, conserving biodiversity, and managing carbon and greenhouse gas emissions. A concerted effort then needs to be brought to bear to implement the strategy and achieve that set of common short- and long-term goals. For that to happen, participants cited the need for a clear roadmap to implementation of the many necessary activities.

Agencies will need to be able to adapt and respond to changing management needs, and policies and permitting processes updated as conditions change and with improved coordination across agencies and programs. Communities and decision-makers need to be engaged and integral to solutions, with a required shift in community perceptions to coexist successfully with fire. Ideally the strategy would have a 25-year horizon, divided into five-year increments. With common, measurable goals identified and an overarching consensus strategy established, we believe that well-coordinated federal and state initiatives–in concert with new philanthropic investments, private sector engagement, and public support–could have a significant impact on limiting catastrophic megafires, increasing our ability to live with beneficial fire, and strengthening ecosystem and community resilience.

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LIST OF MEETING PARTICIPANTS

Marion Adeney, Conservation X Labs

Ken Alex, University of California, Berkeley

Christopher Anderson, Salo Sciences

Michael Anstirman, Arabella Advisors

Thomas Azwell, University of California, Berkeley

Tim Ball, The Fireball Companies

Genevieve Biggs, Gordon and Betty Moore Foundation

Lucy Blake, Northern Sierra Partnership

Maxwell Brodie, Rain Industries

Brian Collins, Intterra

Daniel Correa, Federation of American Scientists

Jonathan Cox, San Mateo County Division, California Department of Forestry and Fire Protection

Kate Dargan Marquis, Gordon and Betty Moore Foundation

Alex Dehgan, Conservation X Labs

Michael Delichatsios, Northeastern University

Shelton Douthit, Feather River Land Trust

Teresa Feo, California Council on Science and Technology

Chris Field, Stanford University

Harvey Fineberg, Gordon and Betty Moore Foundation

Greg Gershuny, Aspen Institute

Kyle Gertridge, Salo Sciences

Erica Goldman, Federation of American Scientists

Michael Gollner, University of California, Berkeley

Waleed Haddad, Wonder Labs

Steve Hamburg, Environmental Defense Fund

Winslow Hansen, Cary Institute

Avery Hill, Stanford University

Alexis Hoffman, Jupiter Intelligence

Tom Ingersoll, Environmental Defense Fund

Daniel Joannes, Truckee Donner Land Trust

Chris Justice, University of Maryland

Lara Kueppers, University of California, Berkeley and the Lawrence Berkeley National Laboratory

Daniel Kunches, Feather River Land Trust

Andrew Morris Latimer, University of California, Davis

Yiannis Levendis, Northeastern University

Aobo Liu, Northeastern University

Scott Loarie, iNaturalist

David Marvin, Salo Sciences

Julia Merjan, Aspen Institute

Dan Munsey, San Bernardino County Fire Department

Connor Joseph Nolan, Stanford University

Malcolm North, University of California, Davis

Carlton Pennypacker, University of California, Berkeley and the Lawrence Berkeley National Laboratory

Catherine Pollack, Aspen Institute

Bob Roper, Western Fire Chiefs Association

Dan Selz, XPRIZE Foundation

Robert Shear, Zonehaven

Kristen Shive, The Nature Conservancy

Steve Sickler, Zonehaven

David Solomon, Good Machine

John Svahn, Truckee Donner Land Trust

Brent VanKeulen, Western Fire Chiefs Association

Alexandros Venetsanos, National Center for Scientific Research Demokritos

Dave Winnacker, Moraga-Orinda Fire District

Ed Wishnow, University of California, Berkeley

Brittany Zajic, Planet

Andrew Zolli, Planet

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