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Fitting the solutions to the problems in managing extreme wildfire in California

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Abstract

Agencies are busy within California developing prioritization strategies to increase the pace and scale of forest treatment in an effort to reduce damage to ecosystems and people by large severe wildfire. A tacit assumption of this effort is that building forest resilience to wildfire will resolve California's extreme wildfire challenge. Specifically, the management focus is on coniferous forests where there is abundant evidence of increased tree density and a history of timber production. However, much of the state is covered by non-forested ecosystems, which is also where a lot of structure loss has occurred. We use more than twenty years of wildfire data in California to identify the relative proportion of wildfire area, ignitions and the number of structures destroyed by wildfire categorized by vegetation type. Using five general categories of vegetation (annual dominated, shrubland, woodland, mixed hardwood forest and coniferous forest) we show that a majority of area burned, ignitions and the vast majority of structures damaged by wildfire occur in vegetation types other than coniferous forests. Comprising 19% of the vegetation of California, coniferous forests garner the lion's share of interest in management strategies to reduce the adverse impacts of wildfire. Simply summary statistics clearly show, however, that most of the damage from fire is in systems where forest management is not likely to result in increased wildfire resilience.

Introduction

California led the country in both the total number and total area burned in 2020 (www.nifc.gov). California is consistently ranked as the state with the most fatalities, largest wildfire-related loss of structures, and high suppression costs (https://iii.org/fact-statistic/facts-statistics-wildfires). As wildfire area burned and associated property losses accelerate, much attention has turned to how to manage California's natural ecosystems toward higher fire resilience. California and the federal government have engaged in initiatives (e.g., https://gov.ca.gov/2020/08/13/california-u-s-forest-service-establish-shared-long-term-strategy-to-manage-forests-and-rangelands/)) and teams (e.g., California Forest Management Task Force, https://fmtf.fire.ca.gov/, Tahoe-Central Sierra Initiative, https://sierranevada.ca.gov/what-we-do/tcsi/) to find solutions for the wildfire challenge. These efforts focus on vegetation management to reduce fuels, with numerous calls to amplify mechanical thinning and prescribed fire within forested ecosystems (Kalies and Kent 2016, Little Hoover Commission 2018, Kolden 2019, Miller *et al* 2020). The goals of managing wildfire risk are varied, but include both the protection of life and property and to maintain ecosystem structure and function in fire-maintained ecosystems. California is characterized by a diversity of vegetation types that are highly flammable, fire maintained, and in close proximity to human habitation. These attributes create fire risk that has garnered the attention of the public and politicians. But, like many public environmental crises, there is a tendency for problems to become over-simplified. Understanding the distribution of fire across vegetation types and the

corresponding capacity for management to reduce this risk can lead to a more efficient allocation of limited wildland management resources.

Our focus is on the effort to deploy forest management techniques to reduce the risk of wildlife to property. The debate regarding the best ways to minimize the risks of and damage from wildfires focuses primarily on forests and forest fire. With a common understanding that some forests contain more trees now than they did 50 or 100 years ago, a debate has erupted on the drivers of tree density increase (e.g., Little Hoover Commission 2018) and the best pathway forward for reducing this stand density (e.g., Little Hoover Commission 2018). The debate often revolves around the relative impacts of fire suppression and reduced timber cutting driving these increases (Little Hoover Commission 2018). There remains considerable uncertainty regarding the degree to which reducing stand density actually reduces fire hazard (Keeley and Syphard 2019). All of this assumes an operational hypothesis that wildfire is predominantly a problem that occurs in forests and that changing *forest management* can substantially alter wildfire outcomes. The prominence of fire and structure loss in the southern California chaparral, however, provides an obvious example of how managing wildfire requires more than managing forests.

Understanding the extent to which vegetation management choices (i.e., timber harvest, biomass removal, prescribed fire, managed wildfire) affect risk reduction of high intensity wildfire is important. It is also important to identify areas where treating fuels is likely to be less effective. As California moves to invest millions into forest v management, a fundamental issue is ascertaining what fraction of extreme wildfire that puts lives at risk, burns structures and damages ecosystems is actually found in vegetation types where risk can be reduced through forest management. Here we focus on the most easily addressed of these three issues: assessing the nature of wildfire that places human property at risk.

We sought to answer four simple, but important questions. What fraction of the state of California is in various vegetation cover types, including forests? What fraction of the areas recently burned or ignited in California is in each of these flammable vegetation types? How has that changed through time? What fraction of structures burned in wildfires are found in each of the various flammable vegetation types? Understanding the fraction of the wildfire problem that occurs in the various vegetation types that burn is a precursor to understanding the extent that management choices can reduce the risk of damages through wildfire.
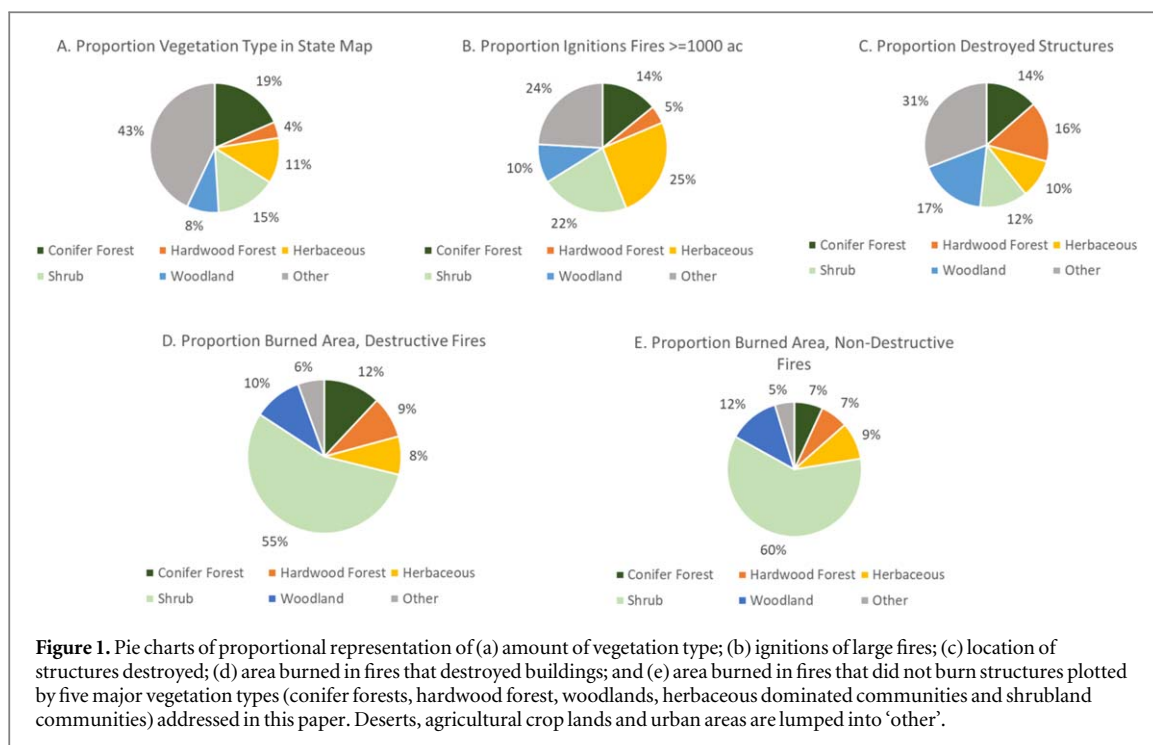
Methods

To answer our questions, we performed a series of calculations by overlaying digital maps and deriving summary statistics within the ArcGIS 10.7 Geographical Information System (GIS).

For estimating the area found by vegetation type, we used a 2015 vegetation map (hereafter 'fveg') developed by the Fire and Resource Assessment Program (FRAP) of the California Department of Forestry and Fire Protection (Cal Fire) (https://map.dfg.ca.gov/metadata/ds1327.html). To develop the map, Cal Fire assembled a range of remote sensing land cover data products and prioritized them according to detail, date of imagery, and consistency. Using a consistent crosswalk system, Cal Fire then classified the maps into the California Wildlife Habitat Relationships (CWHR) System. For this analysis, we used the WHR 13-level classification of vegetation types, including: coniferous forest, hardwood forest, woodland (created by combining hardwood and coniferous woodland), shrub, and herbaceous vegetation. For lower-flammability and only partially vegetated classes, including barren, urban, wetland, water, agriculture, and desert woodland and shrub, we grouped them into a separate 'other' class.

Also provided by Cal Fire, we used the historical overlapping fire perimeter data (https://frap.fire.ca.gov/mapping/gis-data/) to calculate area burned within vegetation types for years 1950–2019 to assess long-term trends, and for 2000–2018 to correspond to the time period for which we had destroyed structure data. For these calculations, we summarized the total area burned for all vegetation types within the boundaries of all wildfire perimeters that occurred within those dates. The source of data for the location of ignitions was from the National

Interagency Fire Program Analysis, Fire-Occurrence Database (FPA FOD) (Short 2017). These data span the years 1992–2015 and include fires of all sizes on all land ownership types. We overlaid these point data on the vegetation map to extract the type of land cover for each point.

We assembled the locations of destroyed structures from a dataset that combined digitized points based on analysis of pre- and post-fire Google Earth imagery and points that were provided via public records request from the Cal Fire Damage INSpection Program (DINS) (Keeley and Syphard 2019). After merging the two datasets, we visually inspected all locations to ensure accuracy and to remove any duplicates. For these data, we extracted the vegetation type at the point location of the building destroyed. We also selected all the wildfire perimeters that corresponded to a fire that had at least one structure destroyed and summarized the area burned by vegetation type for the entire area within the boundaries of the wildfire perimeters. The resulting synopsis

Figure 1. Pie charts of proportional representation of (a) amount of vegetation type; (b) ignitions of large fires; (c) location of structures destroyed; (d) area burned in fires that destroyed buildings; and (e) area burned in fires that did not burn structures plotted by five major vegetation types (conifer forests, hardwood forest, woodlands, herbaceous dominated communities and shrubland communities) addressed in this paper. Deserts, agricultural crop lands and urban areas are lumped into 'other'.

reflected area burned within vegetation types of 'destructive fires.' As a control, we selected all other fires from the same period (2000–2018) and again summarized area burned by vegetation type. As a primarily descriptive assessment, we include no specific statistical analysis of statistical inference.
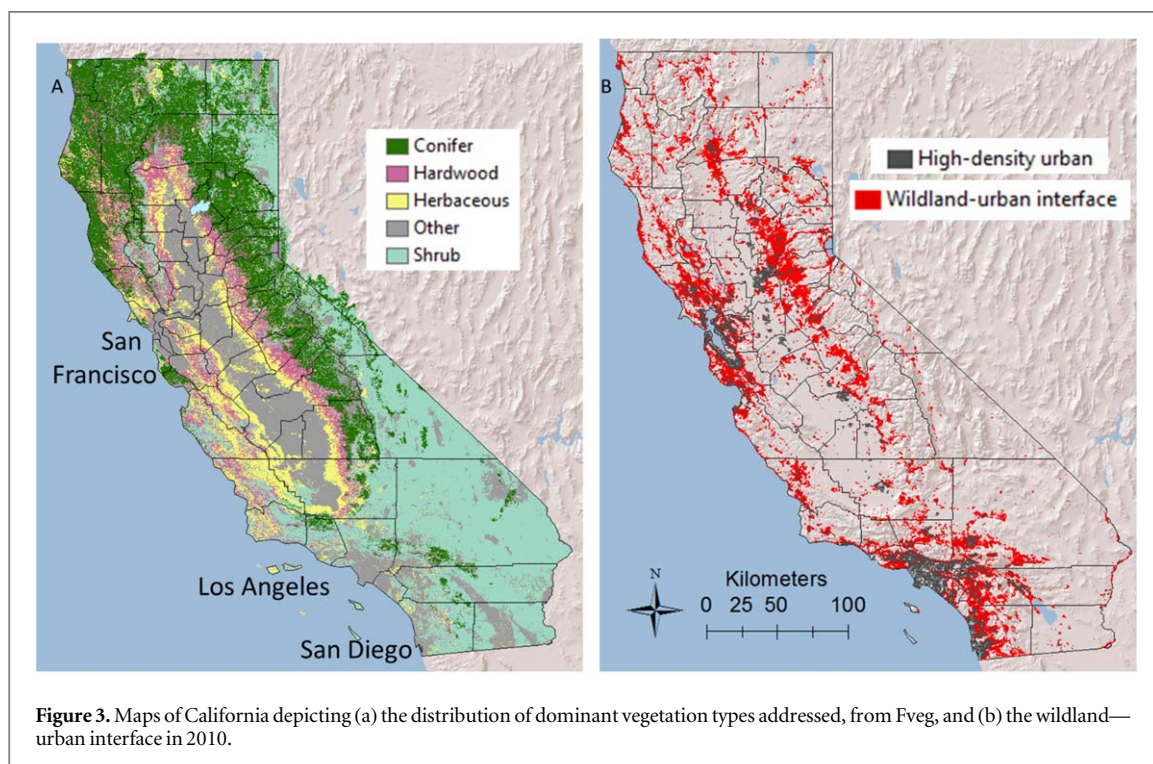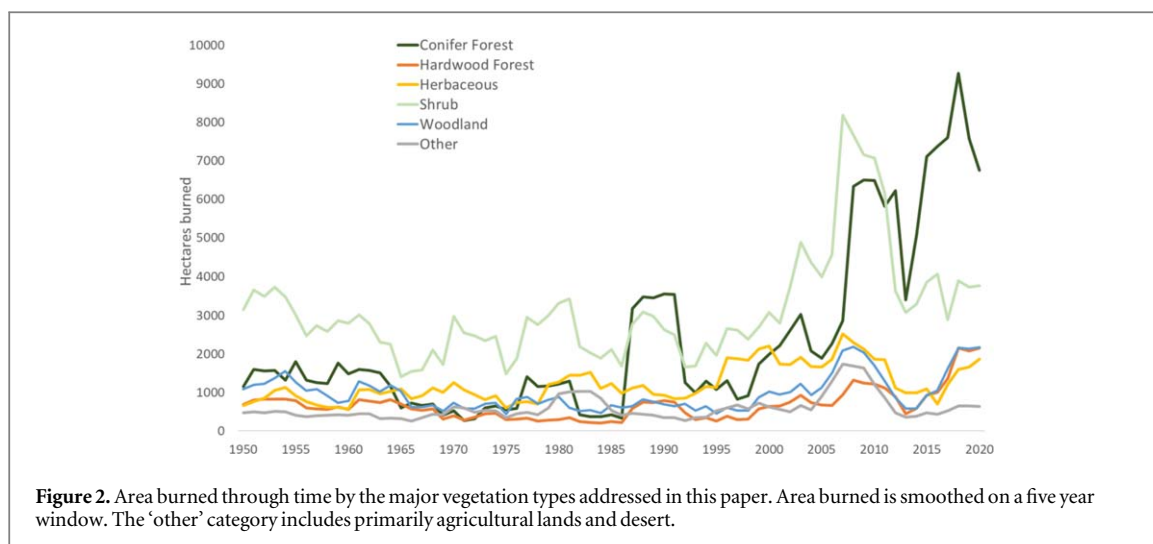
Results

California is characterized by a variety of vegetation and vegetation types (Van Wagtendonk *et al* 2018). A coarse classification scheme places coniferous forest as the largest category of flammable cover types at 19% (figure 1(a)). We place a special emphasis on coniferous forest because more than 99% of timber cut in California is from coniferous forest types (McIver *et al* 2015). Similarly, seed planting, prescribed fire, biomass removal programs all focus largely on coniferous forest types making coniferous forests synonymous with managed forest. Another 38% of California is characterized by four other types of flammable vegetated landscape: woodland, shrubland or grasslands. This leaves 43% of California as relatively non-flammable (urban, row crops, desert and open water) systems (figure 1(a)).

Over the course of good fire records, since 1950, the area burned by wildfire in California has disproportionately been found in shrubland and herbaceous dominated vegetation (figure 2). While wildland fire has increased since 2000 in most vegetation types, fire in coniferous forest has shown the most marked rate of increase (figure 2). Nevertheless, the cumulative acres burned has consistently remained dominated by non-coniferous habitats (figure 2).

An important component of managing wildfire risk is to understand where, when and why fires ignite. While analyzing ignitions fully is beyond our scope here, we can say that ignitions, among those recorded for all wildfire, are over-represented in grassland and shrubland habitats (figure 1(b)) relative to the abundance of those cover types (figure 1(a)).

Examining patterns of structure loss by wildfire provides yet another perspective on management need. The largest number of structures were lost in locations classified as 'other.' This includes residential areas along the wildland-urban interface (WUI). Discerning the vegetation that was burning that led to these losses is beyond the current scope. However, this can be inferred from the natural vegetation types associated with structure loss. The largest fraction of destroyed structures since 2000 in natural vegetation types are found in hardwood forests and woodlands, at their point location (figure 1(c)). Since 2000, 88% of the wildland area burned where structures were destroyed was in non-coniferous vegetation types (figure 1(d)). Fires that destroyed property were, by far, most strongly associated with shrubland habitats (figure 1(d)). Woodlands and grasslands also both exceeded coniferous forest in terms of area burned in destructive fires (figure 1(d)). The relative proportions of vegetation types burned in destructive and non-destructive fires is roughly the same (figures 1(d), (e)).

Figure 2. Area burned through time by the major vegetation types addressed in this paper. Area burned is smoothed on a five year window. The 'other' category includes primarily agricultural lands and desert.

Figure 3. Maps of California depicting (a) the distribution of dominant vegetation types addressed, from Fveg, and (b) the wildland—urban interface in 2010.

Discussion

Understanding the distributional patterns of wildfire across vegetation types is important for several reasons. We address the five focal vegetation types sequentially to better understand measures that might be used to reduce risks from wildfire. We recognize that these are coarse descriptions and, particularly for coniferous forests, there is much variation across sub-types. We further recognize that most large, high intensity fires burn across more than one type, Nevertheless, we felt that a summarization at this scale allows for a useful perspective on managing wildfire risk.

These wildfire summary statistics suggest that while fire in coniferous forests is both notable and increasing, it represents a minority of the total area burned and an even smaller fraction of where structures are burned by wildfire. Since 2000, 88% of the wildland area burned where structures were destroyed was in non-coniferous vegetation types (figure 3). Thus, coniferous forests are not the dominant vegetation type of wildfire (figure 2). In fact, less than 35% of all area burned in the state of California since 2000 has been in coniferous forests. These observations run counter to likely popular impressions left by the 2018 Camp Fire, which partly burned through coniferous forest systems to kill 85 people and burn nearly 19,000 structures. Even in this fire, however, coniferous forest only represented 32% of the area burned, with 55% of the area burned being in hardwood

forest and herbaceous vegetation. In short, human losses are far more common in vegetation types other than the coniferous forests that are under scrutiny for management options to reduce risk.

Many coniferous forest types, particularly in montane regions, historically experienced frequent, low-intensity surface fires (Stephens *et al* 2007). Throughout the 20th century, wildfires in these frequent-fire forests were effectively suppressed. In addition, timber extraction has declined sharply over the past 50 years (McIver *et al* 2015). The consequence has been an increase in number and density of trees (Dolanc *et al* 2014, McIntyre *et al* 2015). This uncharacteristic fuel accumulation has also increased the occurrence of wildfires (Miller *et al* 2009) and increased the frequency of high severity wildfire (Mallek *et al* 2013). Reducing fuel accumulation to increase fire resiliency of coniferous forests would reduce overall fire risk within the state. Nevertheless, this often appears as both the beginning and end of the discussion of wildfire management.

Hardwood forest represents just 4% of habitat area, yet 7% of total area burned, 9% of area burned in destructive fires, and 16% of structures destroyed (figure 1(c)). Although hardwood forests have undergone increases in forest stand density in some areas (McIntyre *et al* 2015), this increase has been less substantial than in coniferous forest types. Further, the management options within this system are limited. The state of California has virtually no infrastructure associated with harvesting hardwood for timber (McIver *et al* 2015). Fuels reduction through mechanical means may be an infeasible strategy in most hardwood dominated systems. Hardwood forests, in general, tend to be less flammable than coniferous forests. As a consequence, these may be good habitats in which to favor early season let burn policies, when fuel moisture makes it less likely to have a large, high intensity wildfire (Boisrame *et al* 2017). Given the lower elevation of hardwood forests, most of these lands are privately owned and found in the wildland- urban interface (WUI) (figure 3). The high fraction of structures destroyed in this habitat relative to total area reflects this pattern. With a limited applicability of fuels reduction, low capacity to prescribe fire on private lands, and low capacity to deploy let burn strategies on private lands, the best possible strategies for reducing risk of losses to wildfire in these vegetation types may be through building fire resilience in the built environment.

In most years (45 out of 69), shrublands were the habitat that showed the most area burned (figure 2), and fires that destroyed property were, by far, most strongly associated with shrubland habitats (figure 1(d)). Shrublands, in contrast to forests, have not experienced increased fuels as a consequence of fire suppression, and in fact, fires in shrublands have increased dramatically relative to historical estimates (Safford and Van de Water 2014). Regardless, although most of the shrubland landscape is currently quite young due to so much fire, fuels are not strongly limiting in the large fires of this vegetation type anyway. Healthy shrublands tend to regenerate quickly post-fire, and empirical analysis shows that wildfire and prescribed fire have do not effectively reduce subsequent wildfire in this vegetation type (Price *et al* 2012). Instead, annual foehn winds coupled with human-caused ignitions are the primary factor (Keeley and Syphard 2019). While mechanical vegetation treatments in forests focus on removing surface fuels, the approach in shrublands is to intentionally convert woody biomass to grassland, which is necessary given there is no understory in chaparral shrublands. While these grassy fuel breaks can effectively increase firefighter access to defend communities (Syphard *et al* 2013), they are also corridors for increased spread of invasive annual grasses (Merriam *et al* 2006). Mechanical treatments of shrublands via mastication also increase the potential for grass expansion (Brennan and Keeley 2017). Observing that ignitions are most skewed above average in herbaceous vegetation, we find that grassland conversion is likely to have the unintended negative consequence of increasing fire frequencies in adjacent highly flammable shrublands by igniting easily near roads, trails, human settlements, or even fuel breaks (Syphard and Keeley 2015) and carrying fire quickly into more intensely burning shrublands. Given the challenge of managing fires in shrublands it seems that a dominant effort should be focused on managing the built environment and ignitions in and around them.

Grasslands and open woodlands are also systems where fuel build-up is not driving increased fire and managing fuels is not a likely solution. Open woodlands are generally grasslands with occasional trees, deriving most of their fuels, and flammability, from grasses. Thus, managing open woodlands would be similar to managing grasslands. Both of these vegetation cover types can have very high fire return intervals and recuperate fuels quickly following fire. Grasslands are easily ignited, highly flammable, and contribute to a positive feedback cycle of fire (Fusco *et al* 2019). In addition to shrublands converting to grass under frequent fire, there is also evidence of and potential for fire-catalyzed type conversion of coniferous forests to shrub- or grass-dominated vegetation types (Coop *et al* 2016, Syphard *et al* 2019a, 2019b, Kerns *et al* 2020). Grassland fires under high winds often move very fast. These systems, similar to shrublands, require managing the human environment in order to reduce risk of damage from wildfire.

These simple analyses demonstrate that, while coniferous forests are strong contributors to wildfire and wildfire damage, fire risk to humans overall is not predominantly a forest issue in California. Well-designed fuel treatment strategies in dry mixed coniferous forests may substantially reduce fire hazard in surrounding areas (Stevens *et al* 2016). Further, fuels management in coniferous forests is likely to have longer lasting positive effects, as coniferous forests accrue fuels more slowly than many other vegetation cover types. Although

vegetation management is also performed in other woody vegetation types, these treatments are more effective at controlling fire behavior under non-extreme weather conditions (Syphard *et al* 2011, Schoennagel *et al* 2017, Brown *et al* 2012) when structures are rarely destroyed (Keeley and Syphard 2019).Thus, we fear that the heavy attention to wildfire in coniferous forests may blind policy-makers to management opportunities that may more broadly confer safety from the damaging effects of wildfire.

The geographical distribution of the human population and assets at risk is, unsurprisingly, also highly heterogeneous (Syphard *et al* 2019a, 2019b). Thus, understanding how to best manage the wildfire problem requires understanding of where management tools such as prescribed fire or mechanical removal of wood fuels provide opportunities to reduce risk, and the majority of fire-prone locations where they do not. Just as addressing the wildfire issue in California requires considering wildfire in all vegetation types, it also requires a focus on people and the built environment. Just as wildfire is not evenly distributed amongst vegetation types, the most damaging impacts of those wildfires (e.g. loss of lives and property) are not evenly distributed across fire-prone vegetation types. Recent trends indicate that the WUI is rapidly increasing in California (Radeloff *et al* 2018), and projected future increases in the WUI are far higher in non-forested areas than forested areas: increasing the risk of damage from wildfire in non-forested areas.

Recent studies have provided empirical evidence documenting the most significant factors explaining structure loss to wildfire via comparison of structures previously destroyed with those that were unburned. Consistently, the results have shown that the most important factors explaining structure loss in California (e.g., Syphard *et al* 2012, 2019, Alexandre *et al* 2016, Kramer *et al* 2018) and elsewhere (Abatzoglou *et al* 2018, Kramer *et al* 2018, Nagy *et al* 2018) are the coincidence of human-caused ignitions with severe wind and weather conditions and the location and pattern of housing development. Studies also show significant protective benefits of homeowner mitigation strategies including defensible space (Syphard *et al* 2013, Gibbons *et al* 2018) and structural characteristics (Syphard *et al* 2017a, 2017b, 2019a). Strategically located fuel breaks around communities allowing firefighter access for defensive strategies may also be helpful (Syphard *et al* 2011). These collective strategies that focus on fire prevention and land planning in the built environment may be a more efficient means to the goal of minimizing human risk to wildfire across all habitats.

Further, as climate changes, we should expect damaging wildfire to become less of a managed forest issue and more of an 'other' flammable vegetation type issue. Predictions of 21st century vegetation type change suggest that coniferous forest extent will be reduced and shift upslope, away from the WUI (Thorne *et al* 2017, Liang *et al* 2017). This will make California's wildfire problem less and less of a managed forest problem. Fire-vegetation interactions accelerate this problem by driving type conversion of forests to other physiognomic types through fire (Keeley *et al* 2019, Coop *et al* 2020). The net consequence is that climate-driven vegetation change may shorten expected fire return intervals, at least in the near term, and reduce the capacity of forest management to manage damaging wildfire.

Principally, a focus on making communities more fire safe (Calkin *et al* 2014, Moritz *et al* 2014) is both a more general, more extensively relevant, and potentially more certain strategy to reduce losses to wildfire. However, our investment in social solutions to wildfire lags significantly behind investment in fixing a vegetation challenge that impacts a minor subset of the vegetation that carries damaging wildfire. California spends roughly $2.5 billion in firefighting each year (Petek 2020). In addition, the budget for reducing fuels and cutting fire breaks is $364 million. In contrast, the budget for improving emergency services is just $122 million, and this includes non-fire emergency services (Petek 2020). The Governor's assessment of the wildfire challenge identifies the Wildland Urban Interface (WUI) as a critical region where most of the fire damage occurs, and this is supported through empirical research (Kramer *et al* 2018, 2019). The number of households in the fire-prone California WUI grew 11% to 2.9 between 2000 and 2012 (Petek 2020). The WUI continues to grow (Radeloff *et al* 2018). Given the importance of the WUI in terms of fire risk, and the lack of capacity to prevent wildfires in the WUI through fuels management in non-coniferous regions, it would make sense to invest in creating safer living spaces in the WUI. Yet, the Governor is proposing just $110 million for 'home hardening', of which $100 is one-time spending (Petek 2020). Considering the scope of the problem in non-managed forested systems, these budget priorities do not align with the magnitude of the problem. If we accept wildfire as a natural component of California's natural vegetation types then the lack of policies and investment in the non-coniferous WUI is setting California up for continued human impacts from wildfires.

Together these observations lead to sobering conclusions. We are not suggesting that we are over-investing in resolving the wildfire challenge in coniferous forests where management may significantly reduce fire risk. There are many good reasons to address fuels in coniferous forests. Fuel treatment has longer lasting impacts than in many other systems, fires may be more likely to drive unwanted ecosystem change in coniferous forests, and the controllability of intense forest wildfire is low. We agree that more needs to be done in forested systems to create resilient ecosystems. However, there is clear evidence that damage to human structures from wildfire is predominantly outside of these managed forests systems. This leads to a clear conclusion that vegetation management, of any sort, may have a limited capacity to significantly reduce risk of property damage due to

wildfire. This observation suggests a need for robust parallel efforts to increase the resilience of human communities that are found in and adjacent to environments that experience frequent fires and that no amount of natural vegetation management will completely resolve risk to human structures.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors. https://map.dfg.ca.gov/metadata/ds1327.html.

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