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Comparing Geography and Severity of Managed Wildfires in California and the Southwest USA before and after the Implementation of the 2009 Policy Guidance

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Abstract: Managed wildfires, i.e., naturally ignited wildfires that are managed for resource benefits, have the potential to reduce fuel loads, minimize the effects of future wildfires, and restore critical natural processes across many forest landscapes. In the United States, the 2009 federal wildland fire policy guidance was designed to provide greater flexibility in the use of managed wildfires, but the effects of this policy on wildfires in the western US are not yet fully understood. Our goal was to compare managed and full suppression wildfires and to also analyze the differences between managed wildfires across space (Arizona/New Mexico and California) and time (before and after 2009) using four metrics for each wildfire: (1) distance to wilderness, (2) distance to the wildland–urban interface (WUI), (3) the percentage of area burned with high severity, and (4) the number of land management agencies. Across the study area, we found that managed wildfires were significantly closer to wilderness areas, were farther from the WUI, had a lower percentage of area that was burned at high severity, and had fewer agencies involved in managing the fire compared to full suppression wildfires. In California, managed wildfires occurred closer to wilderness and had a larger percentage of high-severity burn area compared to those in the southwest US (Arizona and New Mexico). Within each region, however, there were no significant geographic differences between managed wildfires before and after the implementation of the 2009 policy guidance. Despite the greater flexibility of the 2009 policy guidance, the basic geographic properties of managed wildfires in these two regions have not changed. As the climate warms and droughts intensify, the use of managed wildfires will need to expand during favorable weather conditions in order to address the threat of large and uncharacteristic wildfires to people and ecosystems.

Keywords: wildfires; managed wildfire; policy; fuel treatments; California; Southwest United States

1. Introduction

The creation of resilient forests and the prevention of large high-intensity wildfires are focal land management challenges that are faced across the western United States [1,2]. The area that is burned by wildfires has increased over recent decades and is likely to continue to increase as the climate warms and elevated fuel loads persist following more than a century of fire exclusion [3,4]. To meet these management challenges, the pace and scale of fuel treatments need to increase substantially [5–7]. Managers have two broad fuel treatment options to address these issues: mechanical thinning or fire (both wildfires and prescribed fires). While mechanical treatments allow managers to select which trees to remove and create the desired forest structure, such treatments are costly [8] and may be limited by biological, legal, administrative, and/or operational constraints [9]. Prescribed fire may have similar constraints and is usually limited in terms of spatial extent [10]. Managers can also use unplanned natural ignitions for resource benefits in order to improve forest conditions at a landscape scale [11]. In addition to reducing fuel, this option also allows fire to fulfill its natural role in increasing landscape heterogeneity and forest resilience. Natural ignitions are also not subject to air quality regulations and can leverage resources and personnel that are only typically available during the fire season.

Wildfires have an important ecological and cultural history within western US forests [12,13]. Since the creation of the current land management agencies in the 1930s, the value of using fire to reduce fuels has been scientifically established [14]. While prescribed fire can be an effective tool for changing wildfire behavior, factors such as short prescription windows, resource constraints, air quality regulations, and liability concerns can limit its use [15–18]. The need to restore fire as a natural process prompted the use of naturally ignited wildfires in wilderness areas during the 1960s and 1970s as part of the prescribed natural fire (PNF) program [14,19,20]. The PNF program was followed by policy changes that provided increased flexibility within national forests in the 1990s [21], thereby making managed wildfires a key supplemental option for reductions in tree densities and accumulated fuels and to achieve other "resource benefits". Under the PNF program, fire was successfully restored in a number of national parks and wilderness areas [19,20,22].

Prior to 2009, policies in the US required wildfires to be either suppressed or managed for resourced benefits, but not both simultaneously [23]. In 2009, the *Guidance for Implementation of Federal Wildland Fire Management Policy* expanded the response options for wildfire management on federal land in the United States, which allowed a naturally ignited wildland fire to "be concurrently managed for one or more [protection] objectives and objectives can change as the fire spreads across the landscape" [24]. This guidance provided wildfire managers with greater flexibility and more potential opportunities to use natural ignitions (e.g., lightning). Wildfires that are controlled with strategies other than full suppression (hereafter referred to as "managed wildfires") are often used to meet specific resource objectives. Wildfires managed with a full suppression strategy (i.e., "full suppression wildfires") focuses on the suppression of the fire at the lowest cost and with the fewest negative consequences to firefighter and public safety. However, it is important to note that full suppression fires can be used to meet management objectives and, conversely, managed fires can include full suppression strategies. Therefore, the two are not mutually exclusive. Recent research has shown that the 2009 policy guidance, along with other concurrent advances in fire management (e.g., the development of spatially explicit decision support tools), has been associated with an increase in the number of managed wildfires [25]. As the use of managed wildfires expands, it is important to understand the differences between managed and full suppression fires in terms of how and where they burn, in addition to the variations in these patterns across different regions.

Managed wildfires can provide a number of benefits. In terms of fire risk, they can be effective in reducing tree density and moderating fire behavior, particularly in landscapes that have long histories of fire use and in areas with a moderate burn severity [11,20,26]. Ecologically, a study that focused on Yosemite National Park demonstrated that the management of natural ignitions increased landscape heterogeneity and likely improved drought resilience [27]. Other studies have also shown that managed wildfires mostly fall within the historical range of variability regarding burn severity, according to vegetation type and the size of the high-severity patches [28–30]. Across most of the Sierra Nevada, the effects of high-severity wildfires increased from 1984 to 2006 [31]; however, an analysis of managed fires over a 30-year period in Yosemite National Park found no significant changes in the proportions of burn severity class [32]. However, the patterns of high burn severity that are related to fire management strategies and policy guidance changes are still unknown.

Although managed wildfires have a long history of use within federally designated wilderness areas, fuel treatments are also needed outside of wilderness areas. Managed fires can incur political and career risks for those involved, which are associated with smoke, duration, fire intensity, and available resources. Therefore, full suppression is still the dominant wildfire response [25], regardless of the burning conditions and weather forecasts. Increasing the management of natural ignition fires for resource objectives can reduce the risk of future wildfires reaching WUI areas, as well as reducing the severity of fires in neighboring wildlands. There is also potential value in the use of wildfires, including managed wildfires, outside of wilderness areas and closer to more inhabited areas in order to increase fuel treatment benefits across the landscape [5]. Additionally, fuel treatments that are implemented in close proximity to WUI and other tactically advantageous areas (i.e., roads, ridges, etc.) could help to protect many resources that are at risk, reduce the spread of wildfires, and increase opportunities for the use of managed wildfires at a landscape scale [1].

A key challenge for fire management is the need to coordinate management across diverse landowners and managers. Given that wildfires move easily across land ownerships, reducing the number and scale of large high-severity wildfires requires cross-boundary cooperation [33]. The 2009 policy guidance identified the need for wildland fire management agencies to use common standards in order to facilitate effective collaboration, develop agreements to clarify roles and responsibilities, coordinate across levels regardless of where the fire ignited, and ensure fire management planning is intergovernmental in scope and developed at the landscape scale [24]. Although multijurisdictional cooperation is common during full suppression wildfires, it has not typically been necessary during managed wildfires, which have historically tended to occur in wilderness areas that are managed by a single agency [20,34]. However, managed wildfires that are outside of wilderness areas may be more likely to require cross-boundary cooperation during the fire response. Therefore, it is important to determine how agency involvement differs across management strategies, time, and space.

In this study, we used existing fire location and severity databases to evaluate potential regional and temporal differences between wildfire management strategies in terms of proximity to wilderness, proximity to WUI, the prevalence of multijurisdictional management, and burn severity. Our primary objective was to understand whether the 2009 policy guidance changed the geographic characteristics and burn severity patterns of recent managed wildfires in California and the Southwest. Our research focused on the following questions:

(1) How does fire severity, proximity to WUI or wilderness, and the presence of multiple land management entities differ for managed wildfires compared to full suppression wildfires?
(2) How do these factors differ between managed wildfires in California and those in the Southwest region?
(3) How did fire severity, proximity to WUI or wilderness, and the presence of multiple land management entities change among managed wildfires following the implementation of the 2009 policy guidance in California and Southwest region?

2. Materials and Methods

To develop the final wildfire database that was used for our analysis, we used the Monitoring Trends in Burn Severity (MTBS) database. This product maps the extent, size, and severity of all large wildfires across the entire United States, i.e., those greater than 1000 acres (404 ha) in the west and 500 acres (202 ha) in the east [35]. We extracted the MTBS wildfire perimeters for our study area, which included Arizona, New Mexico, and California from 2002 to 2016. We then used the Young et al. (2020) dataset to enrich the

MTBS database. Young et al. (2020) compiled their dataset using Incident Status Summary (SIT-209) from FAMWEB Data Warehouse to determine the dominant wildfire management strategy that was used on 10,040 fires within the western United States between 2002 and 2016. Due to the lack of a common key between the Young dataset and the MTBS wildfire perimeters, a manual procedure was used to match wildfires with similar attributes, including state, year, name, date, and size. We matched 1109 MTBS burn perimeters with the Young et al. (2020) dataset and extracted the management strategies that were used for those wildfires in order to complete our database. For wildfires that were only found in the MTBS database, we used the MTBS to identify the wildfire management strategy when it was available and deleted wildfires that were managed with an unknown strategy. We also deleted wildfires that had more than 50% of their burn area outside of our study area. Following these procedures, we were able to attain data on burn perimeters, severity, and management strategy for 1434 wildfires, which ranged from 405 to 228,107 ha in size.

For each wildfire, we calculated their proximity to WUI and to wilderness areas, as well as the percentage of area that burned at high severity and the number of land management agencies that were involved within the fire perimeter. Wildfires that burned within a designated wilderness or WUI area were assigned a distance of zero, while the closest distance between the wildfire perimeter and the wilderness or WUI area was determined for all other wildfires. We calculated the proximity to wilderness using a spatial dataset of all national designated wilderness areas [36,37]. The wildland–urban interface (WUI) areas were determined using the SILVIS lab dataset [38,39]. The SILVIS lab used a spatial analysis of National Land Cover Data and US census housing data to delineate the areas of WUI into two categories: intermix and interface [39]. For our purposes, we merged both the intermix and interface areas from 2010 to represent a collective WUI area.

Surface Management Agency (SMA) polygon data were acquired from the National Geospatial Data Asset [40] and used to assess the number of jurisdictions that were involved in each wildfire. This dataset covers the continental United States and depicts the agency that has surface land jurisdiction for each particular area. The spatial data that are contained within the SMA layer are a culmination of data that are housed at both federal and local government levels. Each agency classification in the SMA layer was dissolved to form 11 different categories: 7 federal agencies, an "other federal" category, a state category, a local category, and a private/unknown category. The percentage high-severity burn area for each fire was based on the Singleton et al. (2021) wildfire severity dataset. Singleton calculated the relativized differenced Normalized Burn Ratio (RdNBR) for the MTBS perimeters by implementing the burn severity mapping methodology of Parks et al. (2018b) using the Google Earth Engine (GEE) platform [41,42]. The high-severity class was defined as areas with RdNBR values greater than 687, based on field data from all over the Southwest region [43].

To test for the differences in proximity to wilderness, proximity to WUI, and the percentage of high-severity burn area, we used the Empirical Cumulative Distribution Function (ECDF). Using the ECDF as a basis for the analysis, sample medians were compared between strategies (managed vs. full suppression), regions (SW vs. CA), and time (pre- vs. post-2009), while accounting for a non-equal variance between comparative samples using the Huber–White standard error. To examine multijurisdictional collaboration, we used a discrete distribution function (DDF). Populations were compared using a Poisson model with mixed effects and Huber–White standard errors to account for a non-equal variance between comparative samples. For all statistical analyses, we used an α level of 0.05.

3. Results

Our results included 1180 full suppression and 254 managed wildfires across the two regions between 2002 and 2016.

3.1. Comparing Managed and Full Suppression Wildfires

Compared to managed wildfires, the median full suppression wildfire was significantly further away from wilderness areas ($p = 0.011$), significantly closer to WUI ($p < 0.001$), and had a significantly greater percentage of high-severity ($p < 0.001$). Approximately 20% of full suppression and 30% of managed wildfires burned within wilderness areas, but full suppression wildfires were more likely to be further away (Figure 1a). Almost all (98%) managed wildfires, but only 83% of full suppression wildfires, burned within 50 km of a wilderness area. Similarly, nearly all wildfires, whether managed (98%) or full suppression (97%), burned less than 20 miles away from WUI; however, full suppression wildfires were generally closer. In total, 36% of full suppression wildfires burned within WUI areas (distance to WUI = 0), while less than 9% of managed wildfires did (Figure 1b). More than half of all wildfires (both managed and full suppression wildfires) burned less than 5% of the area at high severity. Nearly 89% of managed wildfires and 67% of full suppression wildfires burned less than 20% of the area at high severity (Figure 1c).

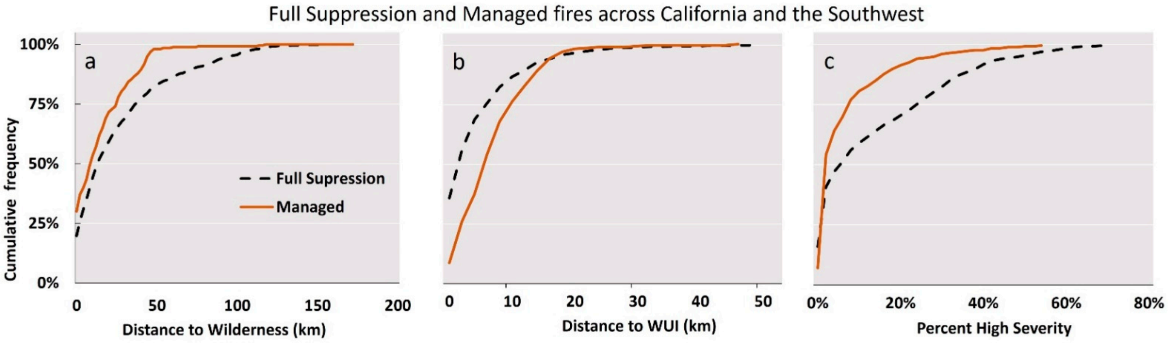

Figure 1. Comparison of full suppression ($n = 1180$) and managed wildfires ($n = 254$) based on (**a**) distance to wilderness, (**b**) distance to WUI, and (**c**) the percentage of high-severity burn area within the entire study area, which included the Southwest (Arizona and New Mexico) and California. Managed fires were closer to the wilderness, further from WUI, and had a smaller percentage of high-severity burn area.

Compared to full suppression wildfires, managed wildfires involved significantly fewer management jurisdictions ($p < 0.001$). Most full suppression wildfires (71%) involved one or two management jurisdictions, while most managed wildfires (58%) were within a single jurisdiction (Figure 2a). At the maximum, full suppression wildfires burned across as many as eight separate jurisdictions, while managed wildfires burned across five jurisdictions.

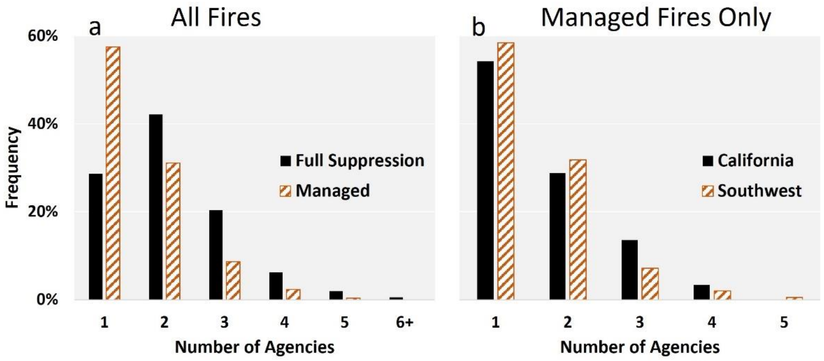

Figure 2. Comparisons of the number of land management agencies involved per fire between (**a**) fire management strategies (full suppression and managed wildfires) and (**b**) regions (California and the Southwest; for managed wildfires only). Full suppression wildfires in our study area included significantly more agencies compared to managed fires. Managed wildfires in California and the Southwest did not differ in terms of the number of agencies that were involved.

3.2. *Comparing Managed Wildfires in California and the Southwest*

Our period of analysis (2002 to 2016) included 59 managed wildfires in California and 195 in the Southwest. Managed wildfires in California showed different characteristics to those in the Southwest. Compared to those in the Southwest, the median managed wildfire in California was not significantly different in terms of distance to WUI ($p = 0.538$) but was significantly closer to wilderness ($p < 0.001$) and had significantly more area burned at high severity ($p < 0.001$). Almost 73% of all managed wildfires in California burned within a wilderness area, which was significantly different from the Southwest, where 17% of managed wildfires burned in wilderness (Figure 3a). The geographic characteristics of managed wildfires in relation to WUI were not significantly different between California and the Southwest (Figure 3b). In total, 36% of managed wildfires in California burned less than 10% of the area at high severity while 87% of managed wildfires in the Southwest burned less than 10% of the area at high severity (Figure 3c).

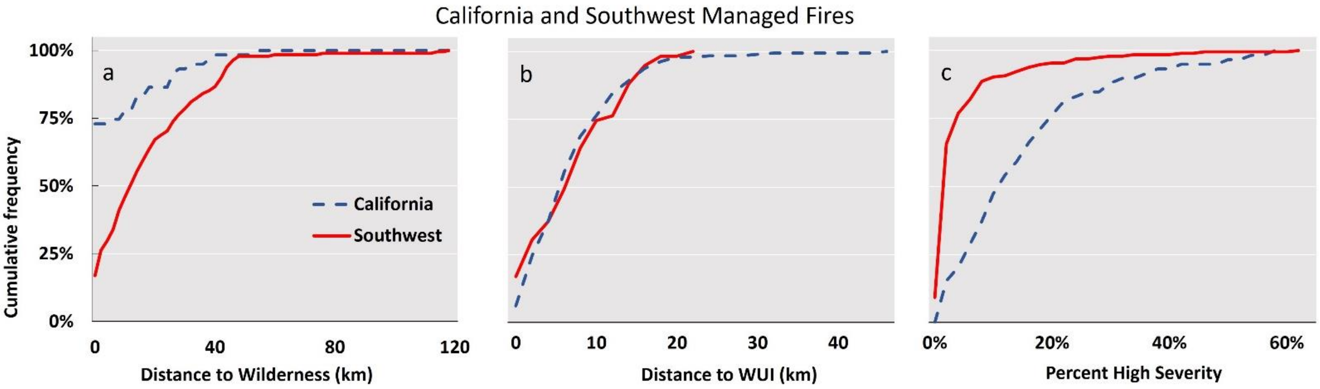

Figure 3. Comparison of managed wildfires in California ($n = 59$) and the Southwest ($n = 195$) based on (**a**) distance to wilderness, (**b**) distance to WUI, and (**c**) the percentage of high-severity burn area. Managed wildfires in California were closer to the wilderness and had a smaller percentage of high-severity fire but were not different in terms of distance to WUI compared to managed wildfires in the Southwest.

Managed wildfires in the Southwest involved significantly fewer management jurisdictions compared to managed wildfires in California ($p < 0.001$); however, the difference was small. On average, a managed wildfire in California involved 1.08 jurisdictions compared to just one management agency for a managed wildfire in the Southwest (Figure 2b). However, at the maximum, managed wildfires in California had as many as four jurisdictions involved, while managed wildfires in the Southwest involved five jurisdictions.

3.3. *Managed Wildfires Pre- and Post-2009 Policy Guidance*

3.3.1. California

Within California, our analysis included 42 managed wildfires from 2002 to 2008 and 17 from 2009 to 2016. Most managed wildfires in California, pre- (71%) and post-2009 (76%), burned within a wilderness area, at least in part (Figure 4a). Most were also within 20 km of wilderness, both pre- (86%) and post-2009 (88%). Similarly, at least 70% of managed wildfires were within 10 km of WUI before and after 2009. In terms of fire severity (Figure 4c), the median (50th percentile) was 14% of the area being burned at high severity for managed wildfires in California pre-2009 and was not significantly different ($p > 0.496$) from the post-2009 median (11% high-severity burn area). Compared to pre-2009 managed wildfires in California (Figure 5a), post-2009 managed wildfires involved significantly fewer management jurisdictions ($p < 0.001$), but with a small practical difference of only 0.01 fewer jurisdictions compared to pre-2009. For each management jurisdiction that was associated with a managed wildfire post-2009, there were 1.01 management jurisdictions associated with a managed wildfire pre-2009, which represented a trivial difference in jurisdiction engagement. Both before and after 2009, most managed wildfires involved one management jurisdiction; at the maximum, managed wildfires in California involved as many as four jurisdictions pre-2009 compared to three jurisdictions post-2009.

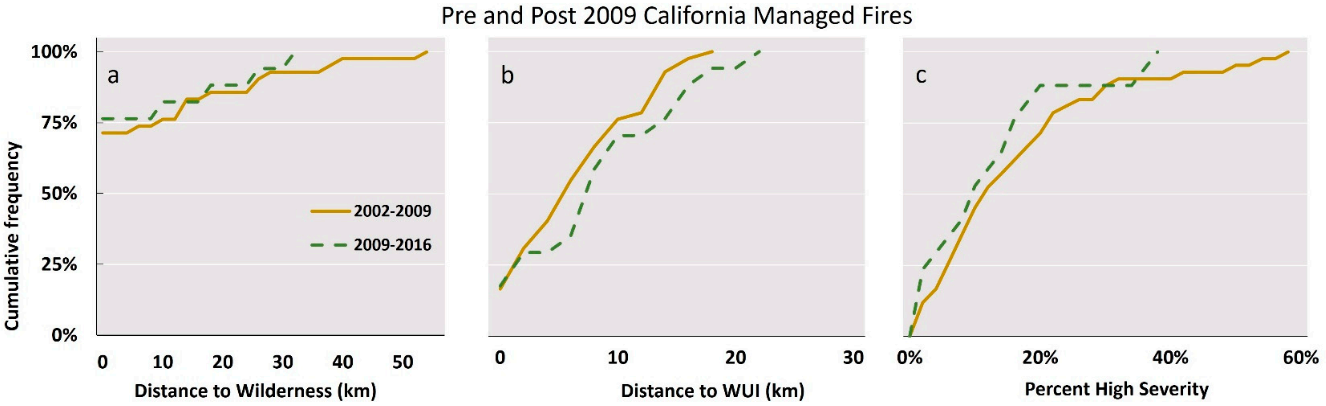

Figure 4. Comparison of managed wildfires in California before (2002–2008) and after (2009–2016) the 2009 policy guidance based on (**a**) distance to wilderness, (**b**) distance to WUI, and (**c**) the percentage of high-severity burn area. The geographic characteristics of managed wildfires in California did not differ between before and after the implementation of the 2009 policy guidance.

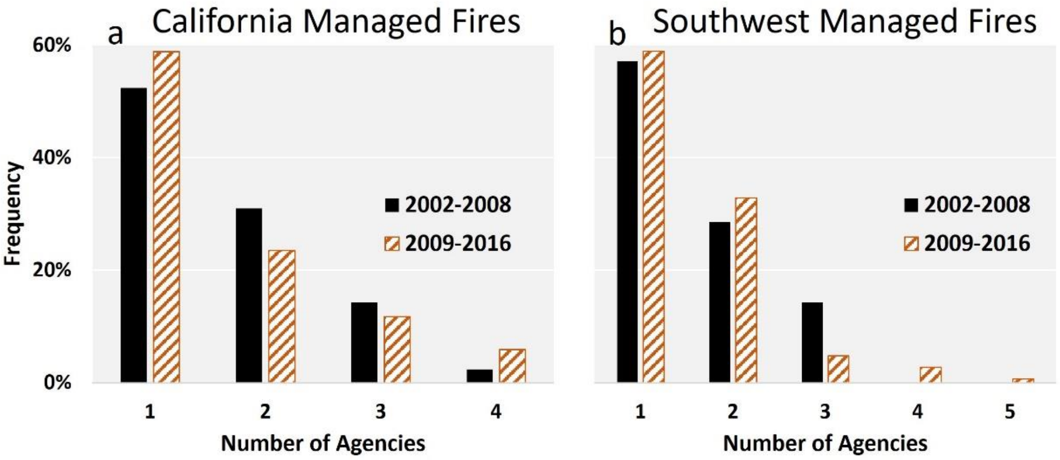

Figure 5. Comparisons of the number of land management agencies involved per managed wildfire before and after the introduction of the 2009 policy guidance in (**a**) California and (**b**) the Southwest. The number of agencies per managed wildfire in California and the Southwest did not change after the implementation of the 2009 policy guidance.

3.3.2. The Southwest

In the Southwest, managed wildfires increased from 49 between 2002 and 2008 to 146 between 2009 and 2016. As in California, managed wildfires in the Southwest were not significantly different pre- and post-2009 in terms of proximity to wilderness ($p = 0.332$) or proximity to WUI ($p = 0.735$). Pre-2009, 18% of managed wildfires in the Southwest burned within a wilderness area, with little change after 2009 (16%) (Figure 6a). From 2002 to 2009, 4% of managed wildfires in the Southwest burned within WUI, which then increased to 7% between 2009 and 2016 (Figure 6b). Most (98%) managed wildfires burned within 20 km of a WUI area, both pre- and post-2009. In the Southwest, the median post-2009 managed wildfire had a significantly lower percentage of high severity burn area ($p = 0.041$) than the pre-2009 median, but the difference was unlikely to have practical implications. Roughly 71% of managed wildfires in the Southwest burned < 5% of the area at high severity pre-2009, which increased to 78% post-2009 (Figure 6c). Compared to managed wildfires in the Southwest pre-2009, managed wildfires post-2009 involved significantly fewer management jurisdictions ($p < 0.001$), although with very little practical effect (Figure 5b). Both before and after 2009, most managed wildfires involved one management jurisdiction. However, at the maximum, managed wildfires in the Southwest involved as many as three jurisdictions pre-2009, which increased to five jurisdictions post-2009 (Figure 5b).

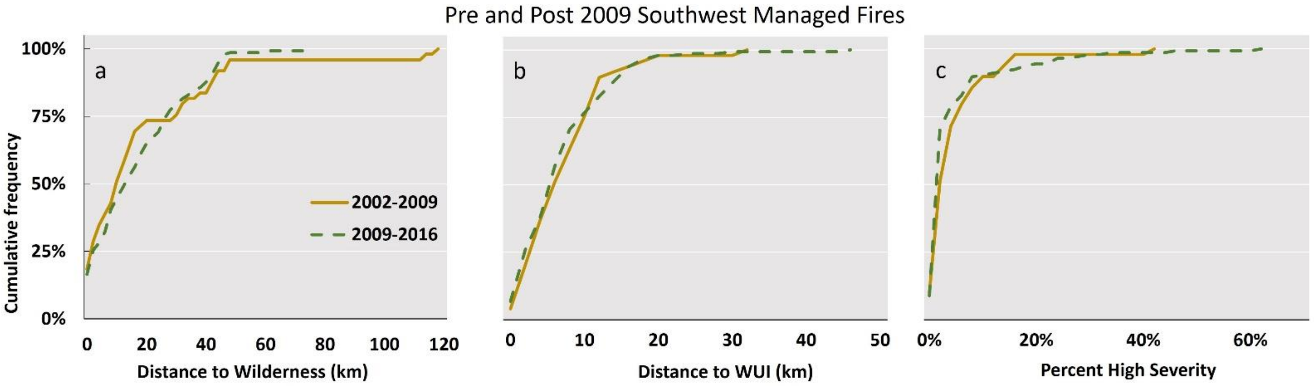

Figure 6. Comparison of managed wildfires in the Southwest before (2002–2008) and after (2009–2016) the 2009 policy guidance based on (**a**) distance to wilderness, (**b**) distance to WUI, and (**c**) the percentage of high-severity burn area. In the Southwest, the geographic characteristics of managed wildfires did not differ between before and after the implementation of the 2009 policy guidance.

4. Discussion

4.1. Strategy Differences

Over the last three decades, the total area that was burned and the area that was burned at high severity in the western United States have significantly increased [43–45]: a pattern that is likely to continue as the climate warms and dries [3]. Increased fire activity has also escalated negative effects on human communities and ecosystems, which has raised important questions about which future we would prefer: an approach that supports the ability to manage wildfires in a way that both reduces fire risk and improves landscape resilience or an approach that continues to attempt to suppress wildfires, despite the recognition that this continues to allow fuels to accumulate and defers fire risk to the future [46]. Advancing this conversation requires an understanding of the context in which managed wildfires are currently used and their effects.

Our results clearly show that wildfires are significantly different depending on the strategies that are used, i.e., managed and full suppression wildfires are distinctly different in terms of where and how they burn. Wildfires are more likely to be managed in order to meet multiple resource objectives in remote wilderness areas and further from the WUI, usually involving a single agency and a lower percentage of high-severity burn area. The lower burn severity that is associated with managed wildfires is likely because these fires tend to occur later in the fire season and under milder weather conditions [25,47]. Our results are generally consistent with prior research, which has shown that managed wildfires are commonly less severe and fall within the historical range of variability regarding burn severity [28–30]. Although high-severity wildfires are a natural part of some forest types, the forests that are burned using managed wildfires in these two regions are primarily adapted to frequent, low-severity fire regimes (i.e., yellow pine and dry mixed conifer forests). Therefore, the reductions in both tree density and accumulated surface fuels that are generally associated with managed wildfires can be considered beneficial in terms of forest condition and future fire behavior [26] because they increase forest resilience, heterogeneity, composition [48], and pyrodiversity [49].

Our findings support prior studies that have documented the aversion of decision-makers to using managed wildfires in close proximity to the WUI and the preference for managed wildfires within wilderness areas [34]. Research has found that wildfires that risk an increased number of houses commonly receive an increased allocation of fire suppression resources [47,50]. In some instances, this increased allocation is driven by potential liability and damage to homes [47], particularly those of high value [51], while in other instances, it appears to be driven by an inflated sense of risk despite the likelihood of fire damage being low [50]. Our results also show that the number of agencies that are involved in managed and full suppression wildfires differs significantly, with a greater number of agencies being typically associated with full suppression wildfires. This reflects the dynamics that have been identified in other studies, which have documented the reluctancy of agencies to manage wildfires for resource objectives (wholly or in part) when they are likely to burn into adjacent agency jurisdictions due a number of factors, including differences in policies (state or federal), lack of coordination or perceived risk [34].

4.2. Regional Differences

Our results suggest that managed wildfires in California are more likely to be within a wilderness area compared to managed wildfires in the Southwest. However, the two regions did not differ in terms of the distance between the managed wildfires and the WUI. In California, the closer proximity of managed wildfires to wilderness areas combined with the lack of difference in distance to the WUI is likely due, at least in part, to the greater amount of land area with wilderness status compared to the Southwest (15% compared to 4.4% on an area basis), as well as the higher proportion of WUI areas (6.4% compared to 2.6% on an area basis). However, in both of these regions, there are large areas between wilderness and the WUI in which managed wildfires could be used as an important fire management tool. The strategic application of fuel treatments (mechanical thinning, prescribed fire, etc.) in close proximity to the WUI and other valuable infrastructures could reduce the potential risk that is associated with managed wildfires outside of wilderness areas [1]. Increased levels of dialogue within communities to clarify decision-making processes around managed wildfires and to identify and address specific local concerns about their use could also be beneficial.

Our results also show a difference in the proportion of high-severity burn area between managed wildfires in California and those in the Southwest. This is likely driven by differences in climate and moisture regimes between California and the Southwest. California has a Mediterranean climate with a unimodal precipitation pattern, where most moisture occurs in the winter and spring [52,53]. Since most managed wildfires in the western United States occur in the fall shoulder season, in which plants are mainly dormant and fuel moisture is relatively low [25], the lack of moisture could lead to higher percentages of high-severity burn areas. On the other hand, the Southwest has a bimodal precipitation pattern in which moisture occurs both in the winter and summer. Therefore, most managed wildfires occur after the summer monsoonal rains when many plants are still growing and fuel moisture is relatively high, which results in lower fire severities [25,52].

4.3. Temporal Differences

Although the number of managed wildfires increased in the Southwest (49 from 2002 to 2008 vs. 146 from 2009 to 2016) while the number in California declined (42 vs. 17), our results show that the geographic characteristics of managed wildfires remained unchanged throughout these periods. In both regions, the geographic properties of managed wildfires, including distance to wilderness, distance to WUI, the number of agencies involved, and the percentage of high-severity burn area, did not change after the 2009 guidance was released. Most managed wildfires still burn in remote locations within or near wilderness areas and away from WUI areas. Similarly, most managed wildfires still predominantly involve only one or two agencies and result in minimal (<5%) high-severity burn areas. These results are in line with Young et al. (2020), who found no overwhelming changes in the number or size of managed wildfires in the Southwest but did find increases in managed wildfires in other regions of the western US. As mentioned by Young et al. (2020), the lack of a temporal change in managed wildfires within the Southwest could be related to the extensive use of managed wildfires in the region prior to 2009, particularly in the Grand Canyon National Park, Saguaro National Park, and the Gila National Forest. Since 2009, however, there has been a pattern of more managed wildfires being used beyond these historical centers. While in California, the decrease in managed wildfires following 2009 is likely due, at least in part, to the extreme drought that this region has experienced since 2009 (2012–2016) and the subsequent high and extensive levels of tree mortality [54], which have contributed to increasingly severe wildfires [55]. Though not the focus of our analysis, our data show that full suppression fires in California are associated with a significant increase in the percentage of high-severity burn area after 2009, from 14% to 26% ($p < 0.001$). Other significant changes in the parameters of full suppression fires over time were not detected in either region.

4.4. Management Implications

Although it is still possible to reasonably distinguish between full suppression and managed wildfires using posterior reporting (Appendix A in [25]), the process is not clear when the incident occurs and both are considered to be "wildfires" following the 2009 Policy Guidance. However, our results show a significant difference between full suppression and managed wildfires in terms of where and how they burn. Due to this, it could be beneficial to develop distinct language protocols, including clear social and ecological objectives, for each type of wildfire in order to improve external and internal communication. A clear distinction and description of managed wildfires, including the underlying objectives and planning processes, could clarify the reasons for different management approaches and increase public comfort and support for the expanded use of managed wildfires beyond wilderness areas.

The increased flexibility in managing wildfires that has been afforded by the 2009 Policy Guidance alone did not significantly change the geographic characteristics of managed wildfires within the two regions that were studied here. Based on our findings, we provide the following considerations for efforts to increase the use of managed wildfires:

(1) Our results show that the prevalence of managed wildfires, which tend to occur during docile weather conditions that are common in the spring and fall [25,47], varies according to region; therefore, prioritizing the availability of resources during the shoulder fire season could facilitate the wider geographic use of this management tool;
(2) Our results also show that managed wildfires continue to be predominantly used in or near wilderness areas and away from the WUI. A greater application of fuel treatments around the WUI and other strategic areas, e.g., those in [9], may be necessary to reduce concerns about the use of managed wildfires close to these areas;
(3) We identified the tendency to limit managed wildfires to a single jurisdiction, which suggests that coordinated land management plans are still needed across adjacent land management agencies [1,5,56].

Other recent research has pointed to additional factors that could support the application of managed wildfires, including the expanded use of modern wildfire analytical tools and decision-making support systems, e.g., those in [57], the development of strategic and adaptive land management and fire management plans [29,56], and additional social science research to better understand the range of social barriers, as well as facilitators, to the use of managed wildfires, e.g., that in [32]. Together, these changes could strengthen the foundations for the expanded use of managed wildfires, which could reduce both fuel loads and tree densities at a landscape scale while also fulfilling ecological needs [58]. Ultimately, managed wildfires of ecologically appropriate severities will need to be an essential part of comprehensive long-term fire and land management strategies.

4.5. Conclusions

Our results indicate that managed and full suppression wildfires are significantly different in terms of how and where they burn. That is, managed wildfires tend to occur closer to wilderness areas and further away from WUI compared to full suppression wildfires. Perhaps more critical is that managed wildfires include greater proportions of low- and moderate-severity fire, which is beneficial in the many dry forest systems of the western US [11,26]. These differences also highlight the need for targeted communication efforts within and among agencies in order to distinguish between the two fire management strategies more clearly. Notably, our results also indicate that, although the 2009 policy guidance has provided more flexibility for the strategies that are used to manage unplanned wildfires, the geographic characteristics of managed wildfires have not significantly changed. As a result, high fuel loads and homogeneous fuel conditions continue to prevail across forest systems within both regions. These conditions will likely result in a continued pattern of large high-intensity wildfires in the future, especially as drought and other impacts of climate change challenge the resilience of fire-adapted forest ecosystems.

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