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Article

Encountering Prescribed Fire: Characterizing the Intersection of Prescribed Fire and Wildfire in the CONUS

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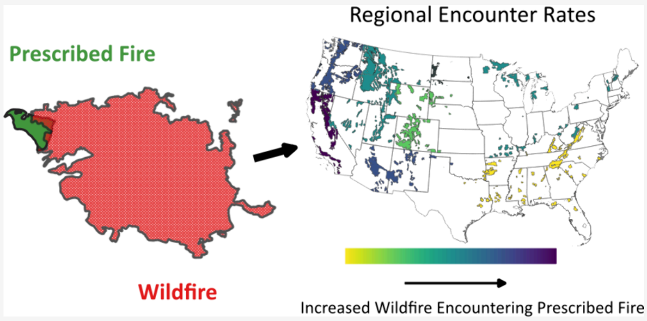
ABSTRACT: Prescribed fire is applied across the United States as a fuel treatment to manage the impact of wildfires and restore ecosystems. While the recent application of prescribed fire has largely been confined to the southeastern US, the increase in catastrophic wildfires has accelerated the growth of prescribed fire more broadly. To effectively achieve wildfire risk reduction benefits, which includes reducing the amount of smoke emitted, the area treated by prescribed fire must come into contact with a subsequent wildfire. In this study, we applied timely and consistent geospatially resolved data sets of prescribed fires and wildfires to estimate the rate at which an area treated by prescribed fire encounters a subsequent wildfire. We summarize these encounter rates across time intervals, prescribed fire treatment area, and number of previous prescribed fires and by region. On all U.S. Forest Service lands across the Conterminous US (CONUS) 6.2% of prescribed fire treated area from 2003−2022 encountered a subsequent wildfire in 2004−2023. Encounter rates were highest in western US forests, which tend to be more impacted by wildfire than the eastern US, and lower in the eastern US. Encounter rates increased with treatment area in the southeastern US but were relatively flat in the northwest. For the CONUS, encounter rates increased with longer time intervals, associated with diminished potential for reducing wildfire severity, between prescribed fire and the subsequent wildfire area burned. Our results provide timely information on prescribed fire and wildfire interactions that can be leveraged to optimize analyses of the trade-offs between prescribed fire and wildfire.



KEYWORDS: *wildland fire, broadcast burn, smoke, spatial encounters, burned area*

1. INTRODUCTION

Over the last 10 years, while the frequency of wildfire has remained relatively constant, there has been a marked increase in the area burned.[1] Although a relatively small percentage of wildfires become catastrophic, since 2000, of the 1.6 million US wildfires, 250 wildfires have burned over 100,000 acres (40,468 ha) with an additional 16 burning over 500,000 acres (202,343 ha).[2] This increase in area burned has led to devastating impacts on some communities alongside broad public health implications due to the substantial increases in the amount of smoke emitted that has had far-reaching impacts on air quality across the US.[3]

There are many factors that contribute to the current wildfire crisis including, but not limited to, years of fire suppression and a changing climate.[4] To address this crisis, land management strategies, with prescribed fire being a key component, are being planned and implemented to curtail the impact of catastrophic wildfire and the corresponding smoke impacts on air quality and public health. In many parts of the US (e.g., Southeast) prescribed fire has been used extensively for ecological benefit while Tribal nations have used it for centuries for both land management and cultural purposes.[5,6] However, the pace and scale of prescribed fire being implemented to address the wildfire crisis serves a different function, with the sole purpose of trying to reduce the risk of catastrophic wildfire in the future[7].[8]

In the process of understanding the role prescribed fire can have on future wildfire risk as well as the corresponding air quality and public health implications, it is important to understand the relationship more fully between prescribed fire and wildfire. Numerous studies conducted to date have

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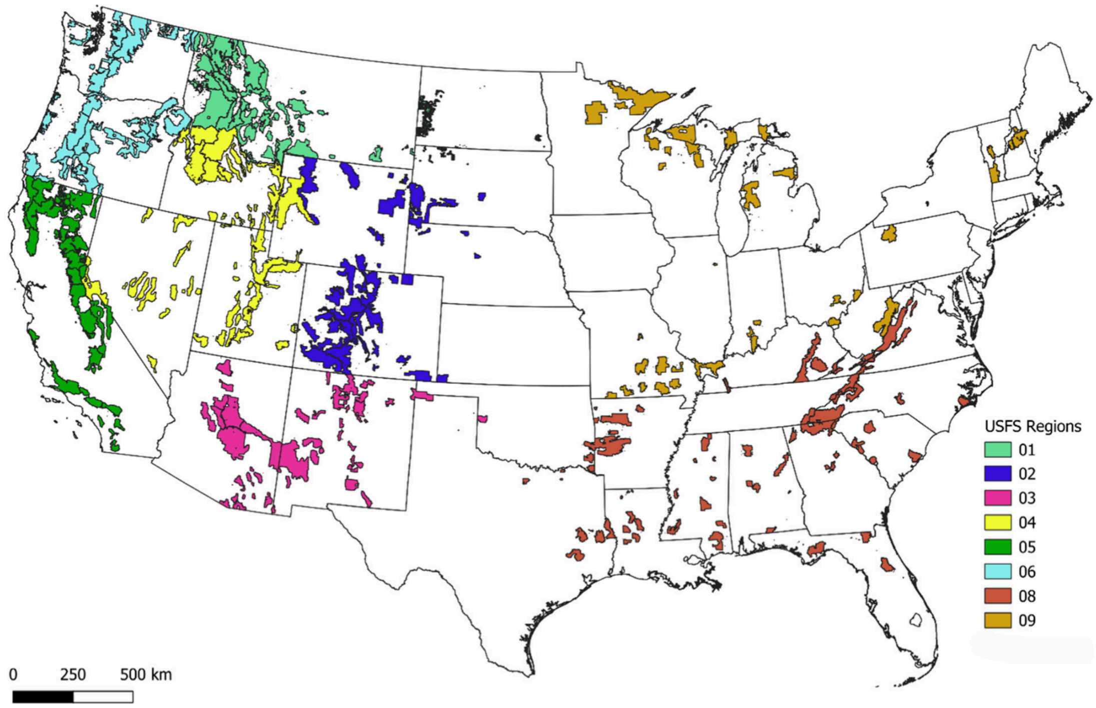

Figure 1. USFS administrative lands by region.

assessed the effectiveness of prescribed fire in reducing wildfire severity, and while there are examples of prescribed fire being able to accomplish this for individual fires, less is known about the effectiveness of prescribed fire at larger spatial scales.[4,9,10] As the overall goal of implementing a broad prescribed fire program is to reduce wildfire risk, gaining an understanding of the factors that can influence such a goal represents important variables that are instrumental in addressing additional prescribed fire-wildfire scientific questions, such as those around smoke and public health.

Previous research has shown that the effectiveness of prescribed fire in reducing the impacts of wildfire is based on numerous factors such as severity of the wildfire that enters treated land, time since treatment, area treated, spatial patterns of treatment, vegetation type, topography, and weather conditions.[11,10,12] While these factors are all important in the ability of prescribed fire to potentially reduce wildfire severity and size, the reductions are ultimately predicated on wildfire encountering previously treated land. The few studies conducted to date assessing prescribed fire effectiveness have focused on specific instances where wildfire intersected with previously treated land.[13,14] However, this type of approach ignores the fact that uncertainty exists as to whether wildfires will encounter land previously treated with prescribed fire and have its intended effect. Few studies have attempted to examine the frequency with which wildfire encounters previously treated land, and all have focused on examining all land management treatments and not individual treatment types. Barnett et al. (2016)[12] examined the encounter rate for all land management treatments (i.e., clear-cut, harvest, mastication, other mechanical, prescribed fire, thin-and-burn, and thinning) and reported a relatively small encounter rate of 6.8% across the continental U.S. in a study focusing on federal land treated from 2000−2013. The encounter rate was found to vary across ecoregions and as the size of the treatment area increased above 200 ha, but only 1.4% of treatments examined were found to be above that size threshold.[12] The results of Barnett et al. (2016)[12] are consistent with those of Rhodes and Baker (2008)[11] that estimated between an ∼7−16% probability of wildfire encountering land treated in ponderosa pine forests in the western U.S. within 20 years of treatment. Overall, both studies indicate a small encounter rate between wildfire and previously treated land, but it remains unclear how often encounters occur between wildfire and prescribed fire, specifically.

As the amount of land treated with prescribed fire will increase over the next 10 years to address the wildfire crisis, with nearly 2 million acres (809,371 ha) treated by the U.S. Forest Service in 2023 alone,[15] it is important to understand the potential impact prescribed fire could have on reducing the risk of catastrophic wildfire. To date, no information exists about the frequency with which wildfire intersects with land previously treated with prescribed fire. Without an understanding of the encounter rates, the potential role that prescribed fire can play in reducing the intensity or size of future wildfires is largely unknown. As both prescribed fire and wildfire emit smoke that has well-documented and characterized impacts on air quality and health,[16,4,17,18] such information as the encounter rate will aid in better informing the broader public health impacts of wildland fire (i.e., wildfire and prescribed fire). This information is critically important to fully characterize the relationship between prescribed fire and wildfire. In this study, we examine the encounter rate between wildfire and prescribed fire (which can consist of broadcast burns or pile burns) across United States Forest Service (USFS) lands in the Conterminous United States (CONUS) over a period from 2003−2023. We leverage timely and consistent geospatially resolved wildland fire data sets to determine the encounter frequency across return intervals, regions, and individual forests. Encounter rates were quantified between prescribed fire, assessing broadcast burns alone and broadcast and pile burns combined and subsequent wildfire.

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These rates were estimated by considering the number of encounters and the area of intersection between prescribed fires and subsequent wildfire events. The area of intersection was examined using multiple regional scales. Treatment size and return interval were also evaluated for the impact on estimated encounter rates. The range of conditions examined here helps illustrate the influence of each on the encounter rates and increase confidence in the results for a situation that is challenging to quantify.

2. METHODS

2.1. Selection of Study Regions and Time Periods. The encounters between prescribed fire (i.e., broadcast burns alone and broadcast and pile burns combined) and wildfire were analyzed over USFS administrative lands in the CONUS. USFS administrative lands and their respective area were identified using the USFS Administrative Forest boundaries file[19] [Figure 1]. Although most prescribed fire across the CONUS occurs on private and state lands, approximately 10% of the annual prescribed fire and 20−25% of the wildfire in the US occurs on USFS lands.[20,21] USFS lands are at the forefront of the wildfire crisis, and as a result prescribed fire is set to increase.[7] USFS lands were selected for this analysis based on both the prevalence of wildfire and the expansion of prescribed fire as a fuel reduction method in addition to the availability of a complete and consistent geospatially resolved hazardous fuel treatment record on forest land.[7] A study time period of 2003−2023 was selected based on recency, multidecadal length, wildland fire data quality, and the availability of geospatially resolved wildland fire data.

2.2. Wildland Fire Activity Data. Prescribed fire information was obtained from the USFS Forest Activity Tracking System (FACTS) Hazardous Fuel Treatment geospatial data set.[22] The FACTS data set contains a historical record of polygon representations of fuel treatment projects, including prescribed fires on USFS administrative lands. Fire category fuel treatments in FACTS were subsets of broadcast and pile burn types based on designations in the database. As noted previously, prescribed fire was tracked as a broadcast only and as a combined set of broadcast and pile burns. While both broadcast and pile burns can be classified as prescribed burns in the FACTS database, the distinction in methods is made because the treatments may not be equally effective at reducing subsequent wildfire severity.[23] Treatments intersecting the USFS Administrative Forest boundaries with accomplishment dates between 2003 and 2022 were included in this analysis. The entire recorded treatment polygon was used for determining the extent and area of the prescribed fire treatment. In FACTS the geospatial area of the fuel treatment polygons may not represent the accomplished area specified for every record. This uncertainty in the geospatially defined area relative to the accomplished area is a limitation of using the FACTS polygon data set that was determined to be minor for this analysis based on a comparison of accomplished and polygon area database fields.

A geospatial data set of wildfire activity was derived from fused perimeter, satellite, and ground data. The wildfire event activity developed for estimating fire emissions in the EQUATES data set was used for 2004−2019. These activity data sets were developed using Monitoring Trends in Burn Severity (MTBS)[24] and Geospatial Multi-Agency Coordination Group (GeoMAC)[25] perimeter data, US National Incident Management System Incident Status Summary Form 209[26] fire incident reports, and Hazard Mapping Service (HMS)[27] satellite data. Data was aggregated and fused spatially and temporally using SmartFire 2 (SF2)[28] consistent with methods used for the 2017 National Emissions Inventory (NEI).[29] The 2020−2023 wildfire activity was developed using data sets and methods consistent with those in EQUATES.[30] The final polygons for each wildland fire event were extracted from the underlying SF2 activity database for each year. The annual data was subset into a single geodatabase containing only wildfires with well-defined area and high spatial resolution. These wildfire data sets were selected for their consistent geospatial record of both small and large fires over the spatial and temporal extents of this study. To maximize the confidence of the wildfire information, the data set was further filtered to remove fires that did not have at least two sources of activity data in SF2 reconciliation. The filtered fires included events with a median size of less than 1 ha, where the fire type was difficult to determine, such as those identified only by satellite. Although events were removed, total USFS administrative land area burned by wildfire from 2004−2023 after filtering was 1.4% higher than the USFS wildfire area burned reported by the National Interagency Coordination Center (NICC) based on ICS-209 reports.[21] Alternative wildfire data set options were analyzed for completeness and coverage for a subset of western states, including data sets used as part of the SF2 input data. Individually, these alternative data sets showed inconsistencies in fire perimeters, area, and the number of fires included (Tables S1 and S2) that further indicated support for a fused multisource wildfire data set.

2.3. Determination of Encounter Rates. Encounters by area and count were defined as prescribed fire events (i.e., broadcast burns or broadcast burns and pile burns) whose polygon area geospatially intersected the polygon area of a subsequent wildfire event. This method includes encounters that occur within the same year as the prescribed fire treatment if the treatment occurred prior to the wildfire ignition date. All geospatial intersections and area of intersection calculations were made using an Albers projection (EPSG: 5070).

Rates of encounter were determined at 5-, 10-, and 15-year intervals at the individual forest, USFS region, and CONUS level. Prescribed fire treatment polygons from FACTS were assigned to a USFS forest and region based on the greatest area of intersection with the USFS polygons. The encounter time was calculated as the difference between the year of the first postprescribed fire wildfire and the year of the most recent prescribed fire accomplishment at the encounter location. The 5-, 10-, and 15-year encounter intervals were selected to reflect varying durations of prescribed fire fuel reduction effectiveness[13,10,31] while staying within the time range of the data selection. Encounter rates by area represent the ratio of encounters by area to the prescribed fire area, calculated as the total spatial intersection within each encounter interval divided by the total area treated over the entire time interval for each forest, each region, and across the CONUS. Interval encounter rates (e.g., 5-, 10-, and 15-year intervals) are encounter rates constrained only to those prescribed fires that occurred during years with subsequent annual wildfire data greater than or equal to the length of the interval. For example, prescribed fires during 2005 were included in the 15-year interval calculation because wildfire data was available through 2020, but prescribed fires during 2010 were not included in the 15-year interval because the wildfire data stopped in 2023, 13 years after the prescribed fire. This approach to calculating the

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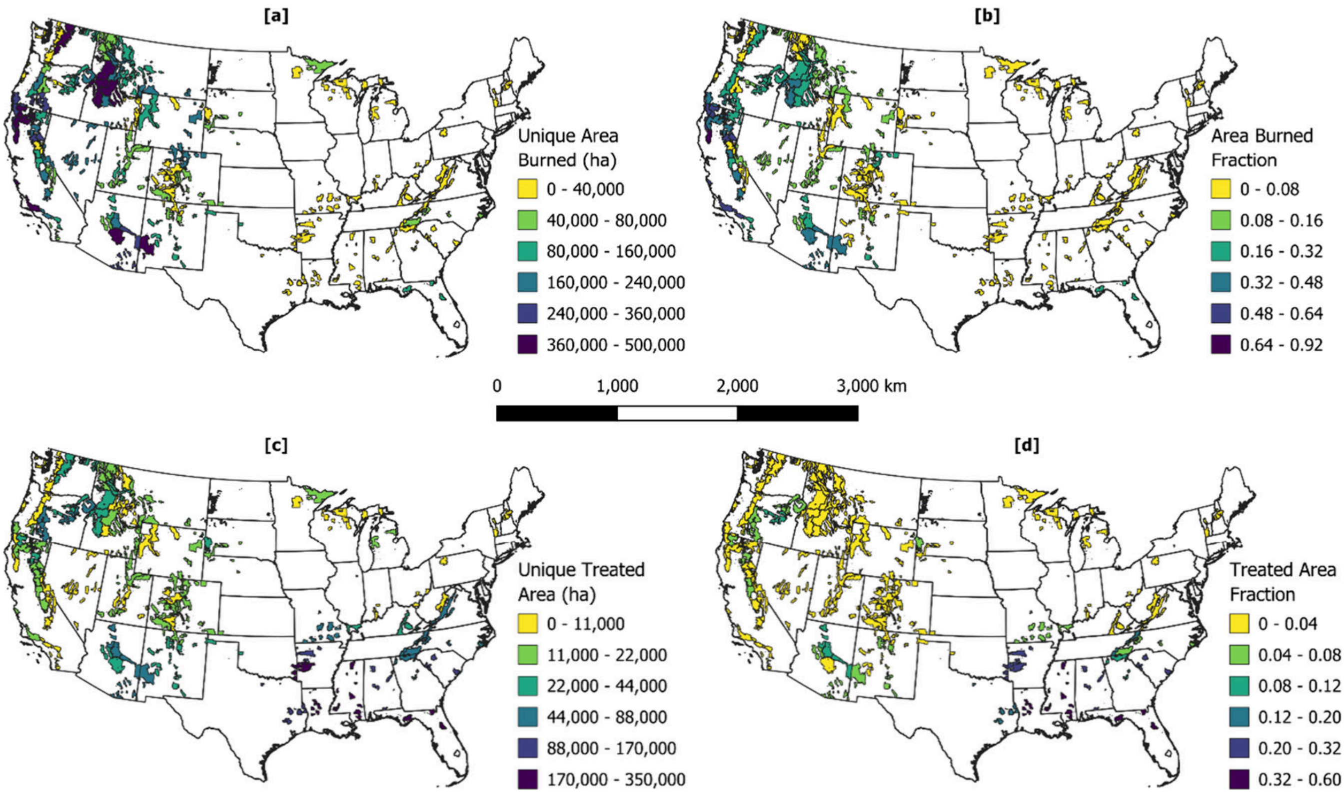

Figure 2. (a) Unique forest area burned by wildfire from 2004−2023. (b) Fraction of forest area burned by wildfire from 2004−2023. (c) Unique forest area treated with broadcast or pile burns from 2003−2022. (d) Fraction of forest area treated with broadcast or pile burns from 2003−2022.

Table 1. CONUS Encounter Rates by Treatment Type and Prescribed Fire Area

Treatment Type	Total Treatments	Total Treatment Area (ha)	2002−2022Encounter Rate (Area)	5-Year Encounter Rate (Area)	10-Year Encounter Rate (Area)	15-Year Encounter Rate (Area)	Mean Area (ha)	Median Area (ha)
Broadcast	34,403	7,118,559	5.7%	3.5%	7.3%	14.2%	207	59
Broadcast + Pile	68,684	7,751,709	6.2%	3.7%	7.7%	14.4%	112	16

interval encounter rates was done to ensure that each prescribed fire had the same number of subsequent years of wildfire data in the interval. Rather than using the area of intersection, encounter rates by count were calculated using the number of prescribed fires encountering a subsequent wildfire divided by the total prescribed fires. The encounter rates by count were also calculated at the same intervals as the encounter rates by area. Encounter rates presented as an overall number include encounters from all prescribed fires contained in the data set, 2004−2023, regardless of the interval or number of years to the wildfire event encounter.

Prescribed fire treatment returns were calculated to determine how often a forest was treated with a prescribed fire. A prescribed fire was classified as a return if the prescribed fire spatially intersected with a preceding prescribed fire. This definition includes partial spatial intersections of any area, regardless of the size. The number of return prescribed fire treatments is the total preceding prescribed fires that spatially intersected with an individual prescribed fire.

3. RESULTS

3.1. CONUS Wildfire and Prescribed Fire Activity. A total of 68,684 broadcast and pile fires that intersected with the USFS forest boundary polygons was included in the 2003−2022 FACTS data selection. These 68,684 prescribed fires accounted for approximately 7.8 M ha of area cumulatively treated across the study duration or 400k ha treated nationally per study year. The broadcast burns accounted for 34,403 of the total prescribed fires and 7.1 M ha of the area treated by prescribed fire. The 2004−2023 wildfire data set contained 9,670 unique wildfire events that intersected with USFS forest polygons, burning a total of approximately 20.3 M ha.

While cumulative area burned or treated is a useful metric that summarizes how much wildfire and prescribed fire is occurring, it does not account for spatial overlap in the wildfire burned area or prescribed fire retreatments. Unique area burned or treated across a forest for the study duration provides a view of how much of a given wildland area was impacted on national-, regional-, and forest-level scales. Over the CONUS, fractions of forest treated with prescribed fire from 2003 to 2022 tended to be higher in the southeast while area burned by wildfires was higher for 2004−2023 in western forests [Figure 2]. Megafires in California and western states played a role in burning up to 92% of an individual forest's total area over the 20 year time period.

3.2. Treatment Encounter Rates at 5, 10, and 15 Years. A total of 480,530 ha of area burned by prescribed fire from 2003−2022 was subsequently burned by a spatially

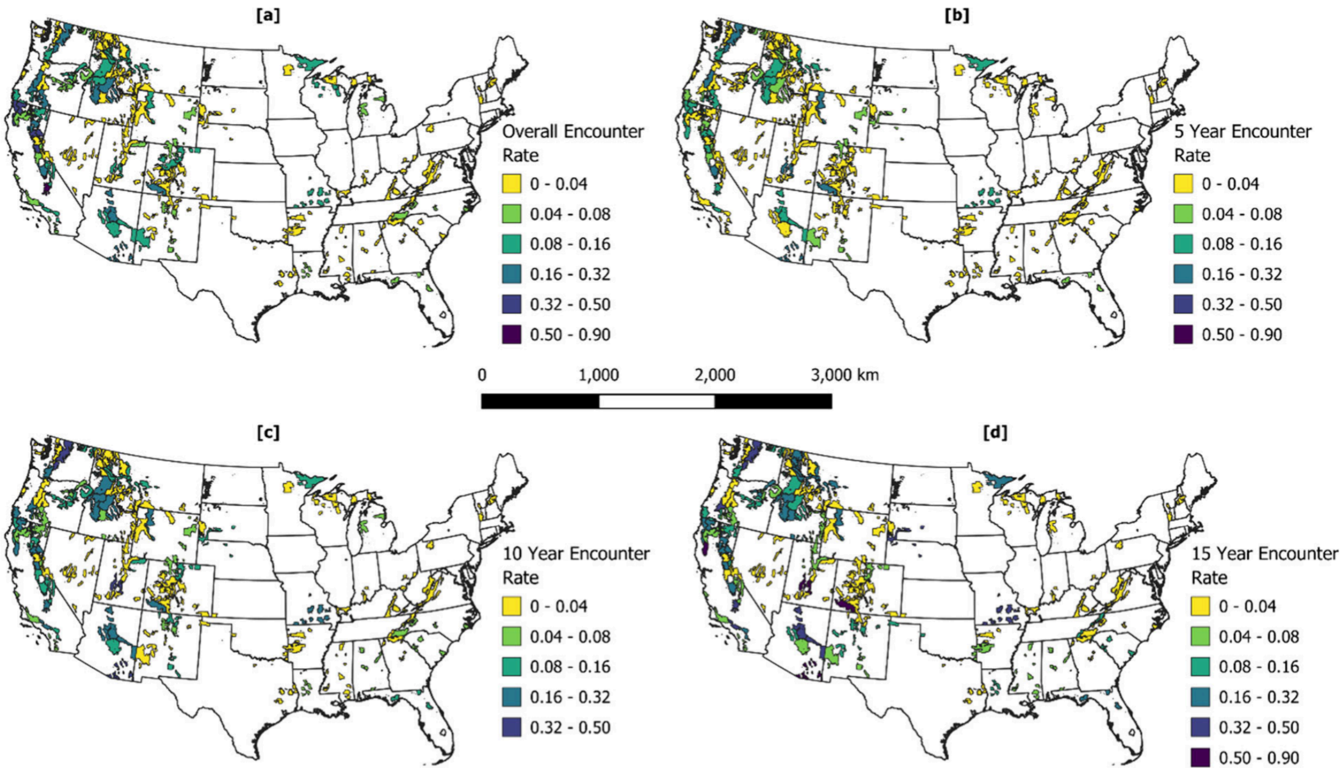

Figure 3. (a) Overall encounter rate by area from 2003−2022. (b, c, d) Encounter rate by area of all prescribed fires (broadcast and pile burns combined) with wildfire for the 5-, 10-, and 15-year intervals.

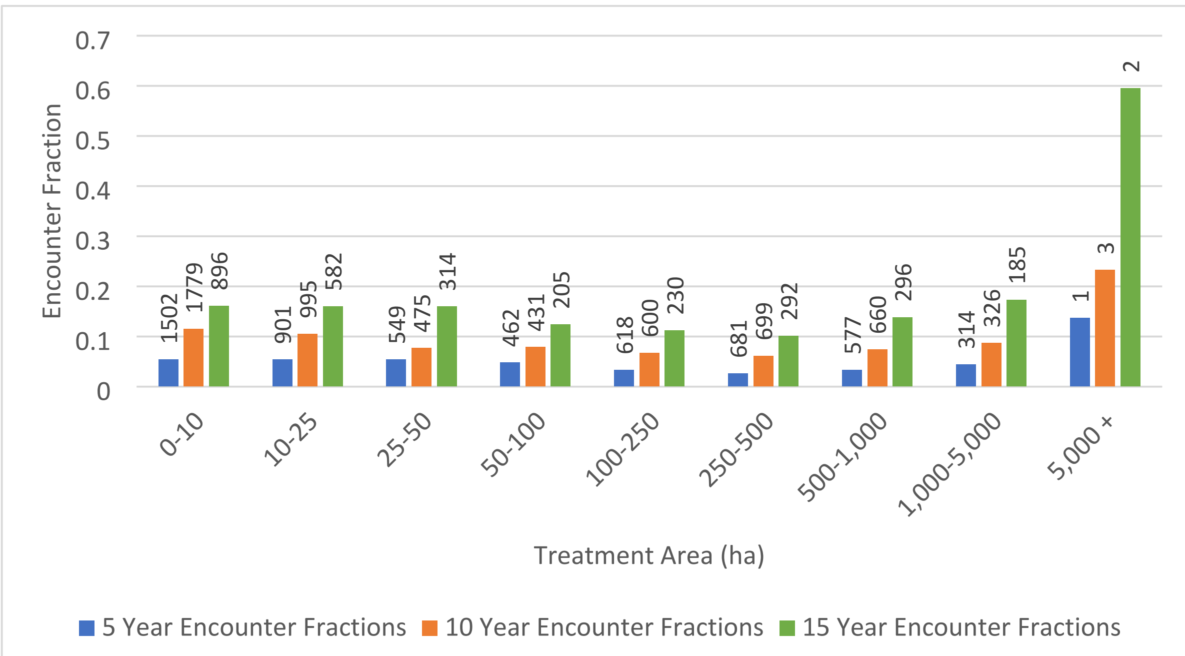

Figure 4. Prescribed fire encounter rates by binned treatment size for 5-, 10-, and 15-year intervals. Labels above bars represent number of prescribed burns in area bin that encountered a subsequent wildfire within the interval.

intersecting wildfire from 2004−2023 for an overall encounter rate by area of 6.2% (Table S3). Out of the 68,684 prescribed fires on USFS land from 2003−2022, 10,610 encountered a subsequent wildfire for an overall encounter rate by count of 15.4%. Of the prescribed fire areas encountered by wildfires, 85% was attributed to broadcast fires. The CONUS interval encounter rate by area of all prescribed fire is 3.7% in 5 years, 7.7% in 10 years, and 14.4% in 15 years [Table 1]. Encounter rates by area were highest in the western US where two forests (Coronado and Mendocino) had 15-year encounter rates of over 80%. Encounter rates by area were lowest in the northeastern and midwestern US where most prescribed fires never encountered a wildfire [Figure 3]. In the west encounters, rates were driven primarily by large wildfires such as those that occurred in California during the 2021 fire season. In the southeastern United States, the encounter rate was primarily determined by the large number of annual broadcast burn prescribed fires.

Individual prescribed fire size in FACTS varied from a hundredth of a hectare to over 12 thousand ha for both broadcast and pile prescribed fires. Most prescribed fires were on the low end of the area size distribution with approximately 38% of all prescribed fires under 10 ha and 70% under 50 ha (Table S4). The median prescribed fire area for CONUS was 16 ha. Broadcast burns had a larger median treatment size than pile burns, with a CONUS median area of 59 ha. The CONUS encounter rate tended to stay flat with prescribed fire area across encounter intervals [Figure 4]. The observed increase in encounter rate for prescribed fires over 5,000 ha is likely skewed by the small number of prescribed fires within this size interval.

Some sections of forests may be subject to multiple prescribed fires to accomplish long-term ecological restoration or fuel reduction goals. Within the CONUS, 35% of treatments had one or more previous treatments. The sites without previous treatments had an overall encounter rate by count of 17.5%, only slightly below the mean encounter rate of 19% for sites with previous treatments (Table S5).

3.3. Regional Treatment Encounters. The encounter rate by area and count of prescribed fires intersecting with wildfires varies regionally across the CONUS (Tables S6−S9). Wildfires in the western United States, defined as USFS regions 1−6, intersecting with prescribed fire on USFS land tended to be larger on average (2,816 ha) than those in the eastern United States (379 ha), defined as USFS regions 8−9. Conversely, mean treatment size was lower in the pile burn dominated western United States (44 ha) compared to the broadcast burns in the southeast (245 ha). These regional variations persisted when examining the mean encounter rate by area. In the West, encounter rates by area where the area of intersection was greater than one hundredth of a hectare had a smaller area (30 ha) relative to areas of intersection in the eastern United States (49 ha). As a fraction of the total prescribed fire, the encounter rates by area in the western US were lower than those in the eastern US except for the 15-year encounter interval where the two regions showed equal rates. This difference in encounter rate by area may be attributable to the regional differences in the prescribed fire size. The relatively flat encounter rates across size intervals in the CONUS [Figure 4] were driven by the prescribed fires in the western US. Prescribed fires in the southeastern US exhibited an upward trend in encounter rate with prescribed fire size, particularly over 500 ha.

The highest 15-year encounter rates by area occurred in western forests with a large fraction of the total area burned by wildfires (Angeles, Sawtooth, Coronado, and Mendocino). For the 5-year encounters by area, forests in the southeastern US (National Forests in Alabama, Florida) exhibited both relatively high encounter rates by area and prescribed fire size. Retreatments were found to be more common in the eastern US where over three times as many prescribed fires overlapped with at least one previous prescribed fire than in the western US.

4. DISCUSSION

As the use of prescribed fire is planned to increase as a tool to reduce the impact of the increase in catastrophic wildfires,[7] it is important to have a baseline understanding of the frequency with which wildfire enters land previously treated with prescribed fire. This information is an important first step in assessing the trade-offs between prescribed fire and wildfire, including quantitative assessments of the ability of prescribed fire to reduce wildfire risk and in more accurately examining the impacts of smoke from wildland fire, at larger spatial scales (e.g., landscape, regional), on air quality and public health.

Prescribed fire frequency is important when considering the encounter rates because the impact of prescribed fire on hazardous fuels and the severity of subsequent wildfires diminishes over time as forests regrow and fuels reaccumulate.[10,32−34] This reduction in fire severity from prescribed fire may last from a few years to multiple decades depending on conditions in the fuel bed.[13] Further, while prescribed fire may be effective at reducing subsequent wildfire severity in the wildfire-prone western US, the benefit can be reduced after 10 years.[35] Periodic return of fuel reduction treatments such as prescribed fire is therefore necessary to maintain effectiveness in reducing subsequent wildfire severity.[36,10] Return prescribed fire treatments were found with approximately one-third of the prescribed fire events between 2003 and 2022 (Table S5), with return treatments more common in the southeastern US where wildfire is historically lower. In the western US where pile burns are more common, approximately 10% of the areas treated with pile burns were subsequently treated with a broadcast burn. Out of all prescribed fires with at least one previous treatment, 62% of the prescribed fire count and 89% of the prescribed fire area were in USFS regions 8 and 9 (eastern US). In contrast to the analysis of all fuel treatments by Barnett (2016),[12] this analysis showed a decrease in the encounter rate as the number of return treatments increased. This difference may be explained by our broad definition of return treatment and the focus only on forms of prescribed fire.

The encounter rates in this study were consistent with the encounter rates reported in previous analyses of all fuel reduction treatments such as Barnett et al. (2016)[12] and Rhodes and Baker (2008).[11] The encounter rate by area tended to increase over time, with the five-year encounter rate by area growing by approximately 33% between the first (2003−2010) and second (2011−2018) half of the included interval years. This result may in part be a result of the increase in annual wildfire burned area across the CONUS,[1] with the western US seeing the largest fraction of wildfire area. In addition, encounter rates by area tended to increase across the interval lengths examined due to there being more subsequent wildfires after a prescribed fire. The trend in increased encounter rates by area should be viewed in the context of the duration of the fuel reduction benefit of prescribed fire, where longer durations may lead to a diminished reduction in wildfire severity. While it was not the focus of this study, wildfires more frequently encounter a previous wildfire than prescribed fire, although these intersections may be less valuable for protecting specific areas considered important and potentially targeted by land management efforts. A CONUS wildfire return rate of 10.3% (Table S10) was calculated from the area of intersection between a wildfire and subsequent wildfires divided by the total wildfire area from 2004 to 2023. This wildfire burned area return rate stands just above the CONUS wildfire-prescribed fire encounter rate by an area of 6.2%.

We examined both broadcast and pile burn prescribed fire methods, with broadcast burns accounting for approximately

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half of the prescribed fires on USFS administrative land across the CONUS but more than 90% of the prescribed fire area. These broadcast burns were concentrated primarily in the southeastern US, consistent with the overall national distribution of prescribed fire.[20] On average, these broadcast burns were larger in treated area than pile burns. Pile burns were more common in the western US than broadcast burns (Table S11); however, mechanical thinning of fuels (and subsequent pile burns of the fuel) has shown to be less effective at reducing fire intensity than broadcast burns.[23] A greater prescribed fire area, such as those associated with southeastern broadcast burns, can lead to a reduction in wildfire severity but only if encountered by a subsequent wildfire.[37]

The data sets included in this study were considered the most complete in terms of spatial resolution, consistency, and recency (Tables S1 and S2). However, this analysis is limited by certain qualities of the data. The FACTS database contains inconsistencies between the geospatial area associated with a prescribed fire and the treated area accomplished that contributes to uncertainty. Further, FACTS contains records for primary wildland management objectives outside of hazardous fuel reduction (e.g., habitat restoration, planting, etc.) that may not have the same properties as prescribed fires with the goal of reducing wildfire risk. In regions such as the southeastern US that have a long history of prescribed fire, this commonly includes prescribed fire for the management of game and wildlife.[6,38] The wildfire event data used fused data from a variety of source types, some of which were not highly geospatially resolved. As a result, smaller wildfire events that relied primarily on ICS-209 ground reports and satellite data, mainly occurring outside USFS administrative lands, were not retained for use in the encounter analysis. The size and location indicate that if reliably characterized and included, the filtered wildfires would have a negligible impact on our results.

The quality and availability of prescribed fire data was an impediment to a broader analysis that should be addressed to help produce a more accurate representation of prescribed fire across the CONUS. The majority of the total prescribed fire area in the CONUS occurs on state and private lands in the central and southeastern US[20,39] where commonly available information on prescribed fires is limited or uncertain.[40,41] Many of these prescribed fires are associated with increased air quality degredation in populated areas, potentially resulting in human health impacts.[42,43] While some effort has been made to improve the characterization of prescribed fire in the southeast,[44] the availability of timely spatially resolved prescribed fire information remains limited. The encounter rates and resulting trade-offs derived from wildland fire activity on USFS lands may not be representative of those on state and private lands due to differences in methods, fuels, and goals.

This analysis details the frequency with which wildfire encounters land previously treated with prescribed fire. Such information is instrumental in addressing additional research questions around prescribed fire, such as its efficacy, as well as gaining a broader understanding of the air quality and public health impacts of wildland fire collectively. From a smoke perspective, better understanding of these intersections will inform future planned trade-off analyses and allow for enhanced risk communication and smoke preparedness.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsestair.4c00228.

Contains additional tables describing the data sets examined for inclusion in this study, regional encounter rates by interval, encounter rates by year of prescribed fire, and encounter rates by the number of previous treatments (PDF)

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Notes

The views expressed in this article are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency. It has been subjected to the Agency's review and has been approved for publication. Note that approval does not signify that the contents necessarily reflect the views of the Agency. No external funding was used for this research.

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