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The influence of wildfire risk reduction programs and practices on recreation visitation

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ABSTRACT

Background. The increasing extent and severity of uncharacteristic wildfire has prompted numerous policies and programs promoting landscape-scale fuels reduction. **Aims.** We used novel data sources to measure how recreation was influenced by fuels reduction efforts under the US Forest Service Collaborative Forest Landscape Restoration (CFLR) Program. **Methods.** We used posts to four social media platforms to estimate the number of social media user-days within CFLR landscapes and asked: (1) did visitation within CFLR Program landscapes between 2012 and 2020 change in a manner consistent with the pattern on nearby lands, and (2) was there a relationship between the magnitudes of specific fuel treatment activities within CFLR landscapes and visitation to that landscape? **Key results.** In aggregate, visitation to the CFLR landscapes changed at a rate mirroring the trend observed elsewhere. Within CFLR landscapes, pre-commercial thinning and pruning had slight positive influences on visitation whereas prescribed burning and managed wildfire had slight negative influences. **Conclusions.** Fuel treatments can have a modest influence on visitation, but we didnot find any wholesale changes in visitation within CFLR landscapes. **Implications.** Social media and other novel data sources offer an opportunity to fill in gaps in empirical data on recreation to better understand social-ecological system linkages.

Keywords: Collaborative Forest Landscape Restoration Program, digital mobility data, ecosystem services, fuels reduction, recreation user-days, recreation visitation, risk reduction program, social media data, volunteered geographic information.

Introduction

Severe, uncharacteristic and frequent wildfire over the last 25 years has led US Federal and state policy-makers to establish landscape-scale forest restoration programs aimed at reducing wildfire fuels, improving ecosystem function, and mitigating risk to human communities from wildfire (Schultz *et al.* 2012; Kooistra *et al.* 2022). One such program, the US Department of Agricultural (USDA) Joint Chiefs' Landscape Restoration Partnership, has alone devoted US$423 million to 134 forest management projects on public and private lands since 2014. Over the next decade, the USDA Forest Service (USDA FS) plans to conduct fuel treatments on 20 Mha of public and private forests as part of its 10-year Strategy to Confront the Wildfire Crisis (USDA Forest Service 2022). These expansive fuel treatment programs are expected to create numerous public benefits including reduced fire severity (Johnston *et al.* 2021), improved quality of municipal water sources (Warziniack and Thompson 2012), and protection of homes (Evans *et al.* 2022). However, it is unclear whether treatments will produce the same positive effects for key ecosystem services from forests, such as the provision of recreation opportunities, or whether adverse effects on recreation trade off with increases in other benefits.

The undeveloped public and private forests that are often the focus of fire risk reduction programs are popular places for outdoor recreation. More than two thirds of the 161 million visits to public US national forests involve recreation in undeveloped, dispersed areas (USDA Forest Service 2023). We know that forest users are often responsive to changes in forest structure and ecological conditions from natural processes and management actions. For example, people give lower aesthetic ratings to forests subject to intensive timber harvests that remove most trees from a forest stand (Ribe 2006; Gunderson and Frivold 2008; Kearney and Bradley 2011), but give more positive ratings to forests where management actions have opened the forest understorey (Starbuck *et al.* 2006; Ribe 2009; Tyrväinen *et al.* 2017). Recreationists also respond to forest changes caused by wildfire. Empirical studies based often on simulated images typically find a severe negative response in hypothetical visitation from fire that kills most canopy trees in a stand (e.g. Hesseln *et al.* 2003) but a less negative response (or even a positive response) to lower-intensity fire that primarily affects the forest floor (e.g. Loomis *et al.* 2001; Starbuck *et al.* 2006). A limited number of *in situ* studies in burned landscapes have found a modest, transient negative response in visitation (White *et al.* 2020), even in areas with high tree mortality (Love and Watson 1992; Borrie *et al.* 2006; Brown *et al.* 2008).

Our lack of knowledge about how fuels reduction treatments influence recreation reflects, in part, a consistent lack of empirical data on recreation use collected at appropriate spatial and temporal resolutions. Federal land management agency programs to collect data on recreation use and visitor behaviour typically have sampling designs developed for periodic reporting at spatial scales larger than the landscapes where forest management activities are happening (Leggett 2017). New methods that rely on volunteered geographic information (VGI) from social media and mobile phone applications have been used to produce reliable estimates of recreation use at finer spatial and temporal resolutions than available from traditional recreation monitoring systems (Wood *et al.* 2020) and to measure visitation response to management actions in settings that lack traditional on-site recreation monitoring (White *et al.* 2022).

We leverage VGI from social media to assess how recreation use is related to fire risk reduction management activities funded under the US Collaborative Forest Landscape Restoration (CFLR) Program. Between 2010 and 2020, the CFLR Program funded 23 landscape-scale forest restoration projects on US national forests. The goal of this research is to improve our understanding of how fire risk reduction programs and fuel treatment activities influence recreation use. Specifically, we pursue two research questions: (1) did aggregate visitation trends within CFLR program landscapes change in the years after project establishment, and (2) within CFLR project boundaries, how did the magnitudes of different fuel treatment activities influence visitation?

Background

The Collaborative Forest Landscape Restoration Program

The CFLR Program was enacted in the 2009 *Omnibus Public Land Management Act* of the 111th US Congress (PL 111–11). National forests selected for inclusion in the CFLR Program receive supplemental funding to plan and conduct forest management activities to reduce the severity of potential wildfires and improve the functioning of forest ecosystems (Schultz *et al.* 2012). After the first CFLR projects were selected in 2010 and 2012, fuel treatments within those landscapes increased rapidly – nearly quadrupling in area between 2011 and 2013 (USDA Forest Service n.d.). Although the area treated on individual CFLR projects varies from year to year and between projects, there have been sustained high treatment levels across the Program since 2013. Over the first 10 years of the program, 1.5 Mha received one or more management actions to reduce vegetation.

Visit estimation

Traditional approaches to measuring recreation use typically involve using mechanical counters on roads or trails, in-person observations, or proxy counts of visitors (e.g. number of hiking permits or campsite occupancy) (Watson *et al.* 2000; Leggett 2017). The USDA FS National Visitor Use Monitoring (NVUM) Program relies on these approaches to estimate recreation use at individual national forest units every five years (English *et al.* 2020). As a result, the USDA FS, and other federal land agencies in the US, lack a national dataset on recreation use at spatial and temporal resolutions necessary for evaluating whether fuel treatments are having positive or negative impacts on recreation use.

Previous studies have overcome the lack of recreation data over large extents and multiple years by leveraging the volumes of VGI that visitors share about their activities on public lands (Wood *et al.* 2013; Di Minin *et al.* 2015). Because VGI is geolocated – meaning visitors are sharing precisely where they partake in recreation – the collection of posts shared on social media platforms provides a source of information on patterns in recreation over space and time. As only a subset of visitors use social media platforms and share media about their trips, there are concerns that the dataset may not represent visitation accurately. Indeed, previous studies have found that less than 10% of visitors to national forests and other Federal public lands in the US share VGI about their trip (Wood *et al.* 2020). Nonetheless, the density of geolocated social media that is shared from a particular location is typically well correlated with the total observed amount of recreation use in the same location and time when it is expressed in user-days of visitation (Wood *et al.* 2013; Tenkanen *et al.* 2017; Wilkins *et al.* 2021). This finding holds across a diversity of settings including national parks (Sessions *et al.* 2016) and national forests (Fisher *et al.* 2018) in the US, and similarly on public lands in other countries (Levin *et al.* 2017; Tenkanen *et al.* 2017; Sinclair *et al.* 2020). Leveraging this finding, previous research has used the density of social media in space to explore how recreation is related with biodiversity (Hausmann *et al.* 2018; Echeverri *et al.* 2022), water quality (Keeler *et al.*

Table 1. Collaborative Forest Landscape Restoration Program projects included in this study (adapted from Butler and Esch 2019).

Project name	Year established	Forest(s)	State(s)	Proposed project area (thousand ha)	Current USDA FS project lands (thousand ha)	Proposed treatment area (ha)
Accelerating Longleaf Pine Restoration	2010	Osceola National Forest	Florida	242.8	121.4	unknown
Amador–Calaveras Consensus Group Cornerstone Project	2012	Eldorado National Forest, Stanislaus National Forest	California	161.9	161.9	15,580
Burney–Hat Creek Basins Project	2012	Lassen National Forest	California	121.4	121.4	28,020
Colorado Front Range	2010	Arapaho–Roosevelt National Forest, Pike–San Isabel National Forest	Colorado	323.7	566.6	12,788
Deschutes Skyline Collaborative Forest Project	2010	Deschutes National Forest	Oregon	121.4	121.4	24,281
Dinkey Landscape Restoration Project	2010	Sierra National Forest	California	80.9	80.9	38,445
Four Forest Restoration Initiative	2010	Apache–Sitgreaves National Forest, Kaibab National Forest, Coconino National Forest, Tonto National Forest	Arizona	971.2[A]	2,387.6	242,812
Grandfather Restoration Project	2012	Pisgah National Forest	North Carolina	121.4	121.4	16,869
Kootenai Valley Resource Initiative	2012	Idaho Panhandle National Forests	Idaho	323.7	202.3	15,957
Lakeview Stewardship Project	2012	Fremont–Winema National Forest	Oregon	283.3	202.3	60,703
Longleaf Pine Ecosystem Restoration	2012	National Forests of Mississippi	Mississippi	161.9	161.9	151,353
Missouri Pine–Oak Woodlands Restoration Project	2012	Mark Twain National Forest	Missouri	121.4	80.9	46,887
Northeast Washington Forest Vision 2020	2012	Colville National Forest	Washington	364.2	202.3	50,341
Ozark Highlands Ecosystem Restoration	2012	Ozark–St Francis National Forest	Arkansas	202.3	121.4	88,178
Selway–Middle Fork Clearwater	2010	Nez Perce and Clearwater National Forests	Idaho	566.6	566.6	21,327
Shortleaf–Bluestem Community Project	2012	Ouachita National Forest	Arkansas and Oklahoma	121.4	121.4	129,500
Southern Blues Restoration Project	2012	Malheur National Forest	Oregon	364.2	364.2	110,066
Southwest Jemez Mountains	2010	Santa Fe National Forest	New Mexico	40.5	40.5	4,209
Southwestern Crown of the Continent	2010	Lolo, Flathead and Helena national forests	Montana	566.6	445.2	80,589
Tapash Restoration	2010	Okanogan–Wenatchee National Forest	Washington	647.5	364.2	68,237
Uncompahgre Plateau Collaborative Restoration	2010	Grand Mesa, Uncompahgre and Gunnison National Forest	Colorado	404.7	242.8	64,750
Weiser–Little Salmon Headwaters	2012	Payette National Forest	Idaho	323.7	323.7	76,890
Zuni Mountain	2012	Cibola National Forest	New Mexico	80.9	80.9	22,662

[A]The Four Forest Restoration Initiative boundary covers the full 2.4 million ha across four national forests, but project activities are focused within a 971 thousand ha core area of ponderosa pine forest.

2015), deforestation (Chen *et al.* 2022), forest stand characteristics (Ciesielski and Stereńczak 2021), and wildfire (White *et al.* 2022), among other variables, at sites that lack traditional visitor count data.

Methods

Our measure of visitation is social media user-days (Wood *et al.* 2013), which represent a visit by one person on one day within a specific geography (in our case, within or outside CFLR project boundaries on USDA FS lands). We calculated social media user-days between 2012 and 2020 for four social media platforms: AllTrails, eBird, Flickr and Twitter. AllTrails is a platform where users can view trail descriptions and maps that focus on outdoor recreation activities, and it allows users to post reviews, trip reports and GPS (Global Positioning System) tracks of their activity at specific outdoor recreation sites. The platform launched in 2010. For this study, we calculated AllTrails user-days from the number of trip reports associated with specific trails. eBird, a citizen science birding platform, is used by naturalists who upload checklists documenting birds that were observed at a particular location and date (Sullivan *et al.* 2009). User-days of eBird visitation were computed as the number of unique users who uploaded checklists within the geographic boundaries of a study site per day. The photograph-sharing platform Flickr and short-text messaging site Twitter are both used by the general population. The popularity of Flickr peaked in approximately 2015 but it continues to be used today. For both Flickr and Twitter, we used geographic coordinates that users have the option to include with their posts and calculated the number of unique users per day per site who shared content on either platform. All data used in this study were from the period before Twitter was renamed X.

Each social media data source was acquired by web-scraping or querying an application programmatic interface (API). The number of AllTrails reviews was enumerated by a program that examined each trailhead's webpage in January 2021. Historical eBird observations were provided by the Cornell Lab of Ornithology in January 2021. Flickr images were retrieved by querying Flickr's API in January 2021. Tweets were retrieved from Twitter's streaming API end-point in real-time from 2012 to 2020.

Our analyses evaluate effects of the 23 CFLR projects established in 2010 and 2012 (Table 1). Projects range in size from less than 81,000 ha (Southwest Jemez Mountains, Dinkey Landscape Restoration and Missouri Pine–Oak Woodlands) to over 400,000 ha (Southwestern Crown of the Continent, Selway–Middle Fork Clearwater, Colorado Front Range, Four Forest Restoration Initiative), but most are between ~121,000 and 243,000 ha. The CFLR projects are located in multiple ecoregions and are diverse in their landscape settings, ownership patterns and scopes of proposed work (Butler and Esch 2019). Fuel treatments were planned for a combined 1.3 Mha (or 20%) of the USDA FS lands within CFLR Project boundaries (Butler and Esch 2019). In most cases, CFLR project boundaries (https://data.fs.usda.gov/geodata/edw/datasets.php) fall within a portion of a single national forest. However, the Four Forest Restoration Initiative CFLR project encompasses the entirety of two national forests and portions of two other national forests, and three additional CFLR projects extend across two or more administrative national forests (Table 1).

Program-level analysis

Our first research question addressed whether the combined effects of the activities associated with focused restoration investment resulted in unique trends in recreation use within CFLR project areas. Specifically, we tested whether the relative amounts of recreation use between CFLR project areas and the nearby USDA FS lands remained stable during the early years of the Program. To do so, we constructed ratios of summed social media user-days within CFLR boundaries to summed social media user-days outside the CFLR project boundaries for the years 2012–2020 and tested whether those ratios changed over time. Our null hypothesis was that the relative amounts of recreation use inside compared with outside CFLR boundaries did not change over time.

For this portion of the analysis, we treated each national forest that participated in a CFLR project as our spatial unit. We divided each of these forests into two spatially distinct polygons: one for the area of the forest inside a CFLR boundary, and the other for the area outside the CFLR project boundaries (Fig. 1). In total, we included 21 CFLR projects across 29 national forests in the program-level analysis. The Apache–Sitgreaves National Forest and Coconino National Forest, whose entire land areas were included in the Four Forest Restoration Initiative CFLR boundary, were excluded. We calculated the total number of social media user-days (summed across the four platforms) for each year between 2012 and 2020 for each portion of the forests. We then calculated the visitation ratio for each forest, for each year, by dividing the number of social media user-days inside the CFLR boundary by the number of social media user-days outside of the boundary. These values varied widely between forests, as expected, because the spatial patterns in recreation within the CFLR forests were highly variable, as were the areas of both the CFLR projects and the footprints of the forest outside the CFLR boundary. Our focus on the visitation ratio accommodates the pre-CFLR forest-specific patterns in recreation use and does not assume *a priori* any specific pattern in the popularity of CFLR areas for recreation. An increase in the visitation ratios over time would indicate that visitation grew more quickly inside the CFLR boundaries than outside the boundaries. We applied a log transformation to the visitation ratios to better approximate normality, then

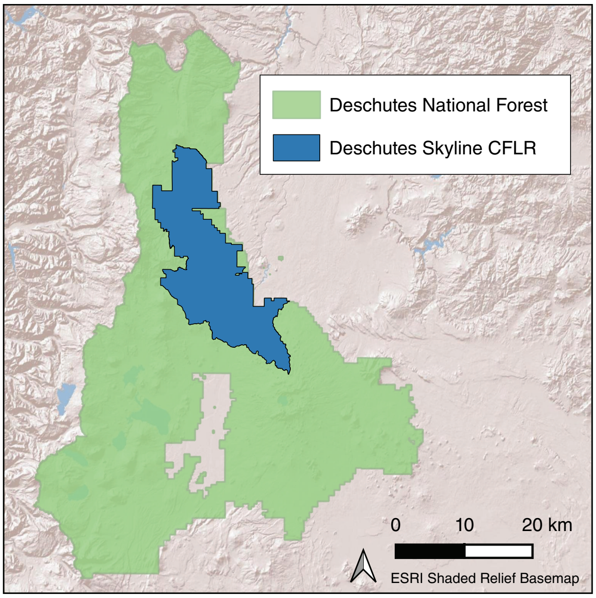

Fig. 1. Area within the Deschutes Skyline Collaborative Forest Landscape Restoration Project (in blue) compared with the area of the remainder of the Deschutes National Forest (in green). Map made in QGIS v 3.30.

used a linear regression to test for change over time in the visitation ratio using R version 4.2.3 (R Core Team 2023). Our model for the program-level analysis was:

$$\ln(\text{Ratio}_{it}) = \beta_0 + \beta_1 \text{Year}_t + \beta_2 \text{Forest}_i + \varepsilon_{it} \quad (1)$$

where Ratio_{it} is the ratio of summed social media user-days within CFLR boundaries to summed social media user-days outside the CFLR project boundaries in forest i during year t, β_0 is the intercept, Year_t is the calendar year (2012–2020), Forest_i is a fixed effect for forest, and $\varepsilon_{it} \sim \text{Normal}(0,\sigma^2)$.

Project-level analysis

We used a linear regression model to understand if variation in annual social media user-days at individual CFLR projects was explained by the magnitudes and types of fuel treatments in that project. Our null hypothesis was that the magnitude and type of treatment would be unrelated to annual recreation use within CFLR boundaries.

We obtained data on fuel treatment activity magnitude and type within the CFLR boundaries from the USDA FS Forest Activity Tracking System (FACTS) (https://data.fs.usda.gov/nrm/briefingpapers/FACTS.pdf). Each FACTS entry represents a single, specific management action that occurred in one place at a specific time. The management action for each entry is selected by the manager from a FACTS library of thousands of management actions. For this research, we reviewed all the FACTS entries for the CFLR project areas, discarded those that were unrelated to vegetation management for fuels reduction, and then collapsed the remaining specific activities into seven management action categories (as used in White *et al.* 2015). We included only completed activities and assigned the calendar year of the treatment based on the activity completion date. The area of the treatment (in acres) was taken as entered in FACTS.

Our seven management actions are the common activities in fire risk reduction programs (Fig. 2) (Hessburg *et al.* 2021; Kooistra *et al.* 2022). *Mechanical surface treatment*, *burning*, *pre-commercial thinning* and *pruning* all focus on removal of vegetation in the forest understorey and lower canopy. *Mechanical surface treatment* generally involves the use of machines to mow shrubs and grasses on the forest floor. *Pre-commercial thinning* typically involves removal of small and mid-sized trees in the understorey and lower canopy of forests using machines or manual labour. In some cases, pre-commercial thinning may involve removing all trees in some portions of a forest stand to create openings in the forest canopy. Trees removed in pre-commercial thinning operations are typically placed into piles for burning, cut up and dispersed across the site, or removed from the site. *Prescribed burning* and *wildfire for resource benefit* (managed wildfire or resource objective wildfire) reduce grasses and brush on the forest floor and sometimes are used to kill small and mid-sized trees. Because prescribed burning activities are planned for and implemented under conducive weather and fuel conditions, those burns are typically intended to have an intensity that does not result in widespread mature tree mortality. Managed wildfire can occur under a broader range of weather and fuel conditions and can yield different stand conditions (e.g. lower basal area and different canopy structure) than similar sites burned in prescribed fire (Hunter *et al.* 2011). Within FACTS, managed wildfires are identified as natural ignitions that were deemed to have met management objectives. *Pruning* involves removing the lower limbs of trees using machines or manual labour. In some cases, pruning can also involve removal of shrub vegetation. *Commercial harvest* and *salvage harvest* involve the removal of trees with larger diameters or those of more desirable species than the trees removed in pre-commercial thinning. *Commercial harvest* treatments are often used to reduce the number of trees in the forest mid-storey, but can involve removal of large trees that reach to the top of forest canopies and removal of all trees in pockets of forest stands in order to create openings with no trees. *Salvage harvests* are used in forests where the trees have been killed by wildfire, insect infestation, wind events, or other natural disturbance. Salvage harvesting is generally not a primary activity in fire risk reduction programs but was present in several of our CFLR projects because a wildfire or insect infestation happened within the project boundary during our study period.

For the project-level analysis, we included the portion of each CFLR project that fell inside national forest boundaries for all 23 CFLR projects. We excluded the portions of the CFLR projects that were not managed by the USDA FS. For

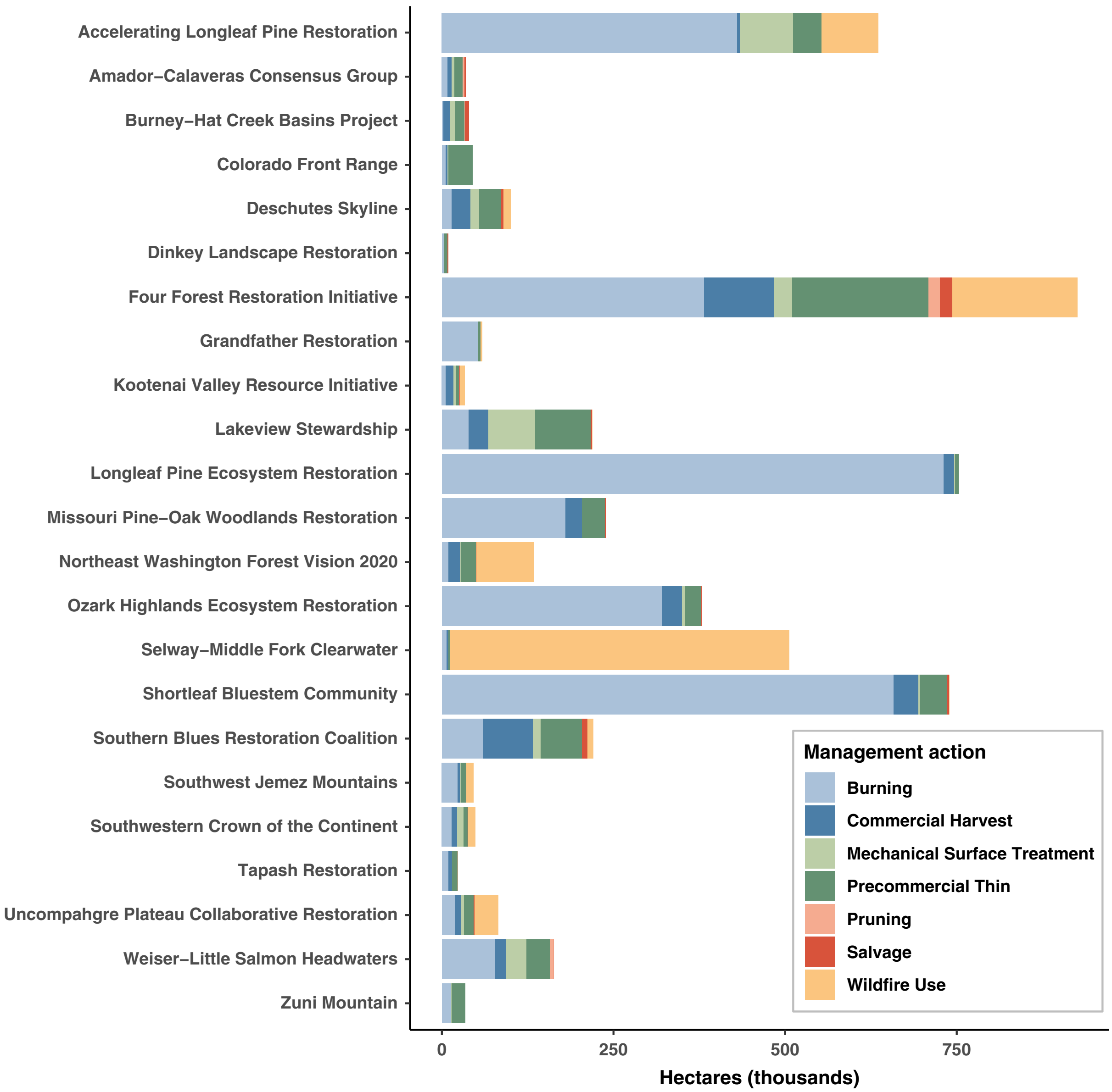

Fig. 2. Total area treated in each management action category between 2010 and 2020 in each CFLR project.

each unit, we calculated the number of social media user-days for each of the platforms for every year between 2012 and 2020. We then measured the relationship between the number of user-days and the magnitude and types of fuel treatment conducted within the unit. We assumed that visitation might respond to fuel treatments in the year they occurred (owing to immediate disturbances to recreation sites, or in the months following the occurrence of the treatment), or in the year following the fuel treatment while impacts are generally still visible on the landscape.

Our model included several controlling variables. First, we included the total area (in acres) of the CFLR project within national forest boundaries. Second, we included a factor variable for which social media platform the user-days were calculated from, the year, and an interaction term between platform and year to account for changes in platform popularity over time. Finally, we included a relative popularity variable to account for differences in the total number of user-days for each CFLR project that reflects the general popularity of the area for recreation, rather than trends over time or in response to the fuel treatments. For each forest that included one of the CFLR projects, we apportioned the number of total visits estimated during the third NVUM cycle (2010–2014) between the national forest lands inside and outside the CFLR boundaries based on the proportion of the total forest acreage. In this way, we estimated the total number of visits to the CFLR project in the year that NVUM sampling occurred. For CFLR projects that included more than one forest, we summed the estimates from the individual forests. Summary statistics of the social media data and the predictor variables are presented in Table 2.

We used a linear model to quantify the effect of the fuel treatments (in acres) and the controlling variables on visitation. As there were zeros present in our dataset, we added one and applied a log transformation to social media user-days and area variables before modelling to better approximate normality. We checked for multicollinearity by calculating pairwise Pearson correlations between the individual predictors (Supplementary Fig. S1; all pairwise correlations $<|0.7|$) and variance inflation factors (all main effect GVIF values <3) using the 'car' package (Fox and Weisberg 2018). Models were fit in R version 4.2.3. The model was:

$$\begin{aligned}\ln(Y_{its}+1) = \beta_0 &+ \beta_1 \mathrm{Year}_t + \beta_2 \mathrm{Platform}_s \\ &+ \beta_3 \mathrm{Year}_t \mathrm{Platform}_s + \beta_4 \ln(\mathrm{Area}_i) \\ &+ \beta_5 \ln(\mathrm{Popularity}_i) \\ &+ \mathrm{Treatment}'_{it}\beta_{6-12} \\ &+ \mathrm{Treatment}'_{i,t-1}\beta_{13-19} + \varepsilon_{its}, \end{aligned} \quad (2)$$

where Y_{its} is the number of social media user-days from platform s at site i during year t, $\mathrm{Treatment}'_{it}$= ($\mathrm{Burning}_{it}$, $\mathrm{CommercialHarvest}_{it}$, $\mathrm{MechanicalSurfaceTreatment}_{it}$, $\mathrm{PrecommercialThin}_{it}$, $\mathrm{Pruning}_{it}$, $\mathrm{Salvage}_{it}$, $\mathrm{Wildfire}_{it}$) is the $\ln(x+1)$ transformed area of the fuel treatment or wildfire that occurred at site i during year t, $\mathrm{Treatment}'_{i,t-1}$= ($\mathrm{Burning}_{i,t-1}$, $\mathrm{CommercialHarvest}_{i,t-1}$, $\mathrm{MechanicalSurfaceTreatment}_{i,t-1}$, $\mathrm{PrecommercialThin}_{i,t-1}$, $\mathrm{Pruning}_{i,t-1}$, $\mathrm{Salvage}_{i,t-1}$, $\mathrm{Wildfire}_{i,t-1}$) is the $\ln(x+1)$ transformed area of the fuel treatment or wildfire that occurred at site i during year $t-1$, and $\varepsilon_{its} \sim \mathrm{Normal}(0,\sigma^2)$.

Results

Program-level analysis

Our statistical model examining trends in visitation within CFLR project boundaries between 2012 and 2020 (Eqn 1) explained the majority of variability in the observed data (adjusted $R^2 = 0.93$). There were significant differences between forests in the relative amounts of recreation use within and outside the CFLR project boundaries (Supplementary Table S1). Our hypothesis was focused on whether the ratios of recreation use inside to outside the CFLR projects changed over time after CFLR establishment and we found that year was not a statistically significant predictor ($\beta = -0.005$, $P = 0.624$) of the ratio. During the first decade of the CFLR Program, there were no statistically significant changes in the relative amounts of recreation use within and outside CFLR project boundaries on those national forests with CFLR projects.

Project-level analysis

The project-level model explained a majority of the variation in the number of annual social media user-days between years and CFLR projects (adjusted R^2 of 0.62; Table 3). As expected, the official NVUM recreation use estimates were positively related to user-days. We found negative time trends (using an interaction term) for eBird, Twitter and Flickr relative to the reference platform AllTrails – indicating that use of these platforms was not increasing as rapidly as use of AllTrails. The total area of the CFLR project was also found to be a negative predictor of user-days, suggesting that larger CFLR projects have fewer user-days relative to their smaller counterparts after controlling for the other variables in our model, notably including the relative popularity of each CFLR project.

Among fuel treatments, prescribed burning in the present year and managed wildfire in the prior year both had a negative influence on user-days in the model (Fig. 3). Managed wildfire in the present year and prescribed burning in the prior year were both negatively related to user-days, but not significant predictors. Precommercial thinning and pruning in the current year (and pruning in the prior year) all had positive influences on user-days. Salvage harvest in the year prior had a positive influence on user-days. We did not find a statistically significant relationship between social media user-days and commercial harvests or mechanical surface treatment. These relationships were robust to a sensitivity analysis, which removed a single anomalous CFLR project (Dinkey Landscape Restoration).

The double-logarithmic structure of our model allows us to directly characterise the responsiveness of recreation to a change in area treated. Social media user-days are most responsive to changes in the area of the CFLR project undergoing pruning. For every 1% increase in the area undergoing pruning, user-days in that year increases by ~0.10%. The influence continues in the year after pruning, at a higher 0.12% increase in user-days. Precommercial thinning yields an increase in user-days of 0.05% for every 1% increase in thinning area in the year of management activity. For prescribed burning, a 1.0% increase in the area burned results in an approximately 0.04% decline in user-days in the year of the burning. That effect becomes not significant in the year after burning. Conversely, the effect of managed wildfire on user-days is not significant in the year of wildfire, but yields a 0.05% decline in the year after the wildfire.

Discussion

For national forests with CFLR projects, we found that visitation trends within CFLR boundaries mirrored the trends outside the CFLR boundaries in the first decade of focused restoration investment under the CFLR Program. This finding is important because numerous Federal and state

Table 2. Descriptive statistics of the variables included in the project-level analysis model, before variables were transformed for modelling (*n* = 844).

Variable	Description	Units	Minimum	Median	Mean	Maximum
Annual UD	Total annual social media user-days (response variable)	User-days	0	52	823	86,793
Year	Calendar year		2012	2016	2016	2020
Platform	Social media platform (AllTrails = reference, eBird, Flickr, Twitter)	Categorical	NA	NA	NA	NA
Total area	Area of the unit (portion of the CFLR within national forest boundaries)	Acres	123,180	423,923	786,510	5,941,313
Burning	Prescribed burning area reported completed in FACTS	Acres	0	1065	8480	85,114
Burning (prior year)	Prescribed burning area reported completed in FACTS in the preceding year	Acres	0	1155	8213	85,114
Commercial harvest	Commercial harvest area reported completed in FACTS	Acres	0	431	1241	14,232
Commercial harvest (prior year)	Commercial harvest area reported completed in FACTS in the preceding year	Acres	0	351	1176	14,232
Mechanical surface treatment	Mechanical surface treatment area reported completed in FACTS	Acres	0	22	738	13,973
Mechanical surface treatment (prior year)	Mechanical surface treatment area reported completed in FACTS in the preceding year	Acres	0	21	732	13,973
Precommercial thin	Precommercial thin area reported completed in FACTS	Acres	0	750	1993	25,109
Precommercial thin (prior year)	Precommercial thin area reported completed in FACTS in the preceding year	Acres	0	698	1925	25,109
Pruning	Pruning area reported completed in FACTS	Acres	0	0	84	4940
Pruning (prior year)	Pruning area reported completed in FACTS in the preceding year	Acres	0	0	83	4940
Salvage	Salvage area reported completed in FACTS	Acres	0	0	136	4786
Salvage (prior year)	Salvage area reported completed in FACTS in the preceding year	Acres	0	0	140	4786
Wildfire use	Natural ignition wildfire meeting management objectives	Acres	0	0	2513	102,648
Wildfire use (prior year)	Natural ignition wildfire meeting management objectives in the preceding year	Acres	0	0	2688	102,648
Relative popularity	Based on apportioned NVUM National Forest visits	Estimated annual visits	41,943	193,782	500,569	4,421,563

Table 3. Coefficient estimates for the project-level analysis model relating annual social media user-days to fuel treatment management actions occurring in the same or prior year in CFLR projects between 2012 and 2020.

	Coefficient	s.e.	*T* value	*P* value
Intercept	−921.4	74.64	−12.345	<0.001
Year	0.453	0.037	12.236	<0.001
eBird (categorical)	588.4	103.1	5.705	<0.001
Flickr (categorical)	1246	103.1	12.084	<0.001
Twitter (categorical)	1221	103.1	11.842	<0.001
Total area	−0.299	0.088	−3.401	<0.001
Burning	−0.041	0.016	−2.528	0.012
Burning (prior year)	−0.026	0.016	−1.665	0.096
Commercial harvest	−0.012	0.020	−0.579	0.563
Commercial harvest (prior year)	−0.025	0.021	−1.19	0.233
Mechanical surface treatment	−0.010	0.019	−0.546	0.585
Mechanical surface treatment (prior year)	−0.007	0.019	−0.367	0.714
Precommercial thin	0.050	0.022	2.228	0.026
Precommercial thin (prior year)	0.043	0.023	1.850	0.0650
Pruning	0.100	0.030	3.360	<0.001
Pruning (prior year)	0.120	0.030	3.980	<0.001
Salvage	0.037	0.023	1.595	0.111
Salvage (prior year)	0.063	0.023	2.710	0.007
Wildfire use	−0.030	0.018	−1.652	0.099
Wildfire use (prior year)	−0.050	0.017	−2.894	0.004
Relative popularity	1.229	0.059	20.805	<0.001
Year × eBird interaction	−0.291	0.051	−5.691	<0.001
Year × Flickr interaction	−0.618	0.051	−12.085	<0.001
Year × Twitter interaction	−0.605	0.051	−11.826	<0.001

Adjusted R^2 = 0.62.

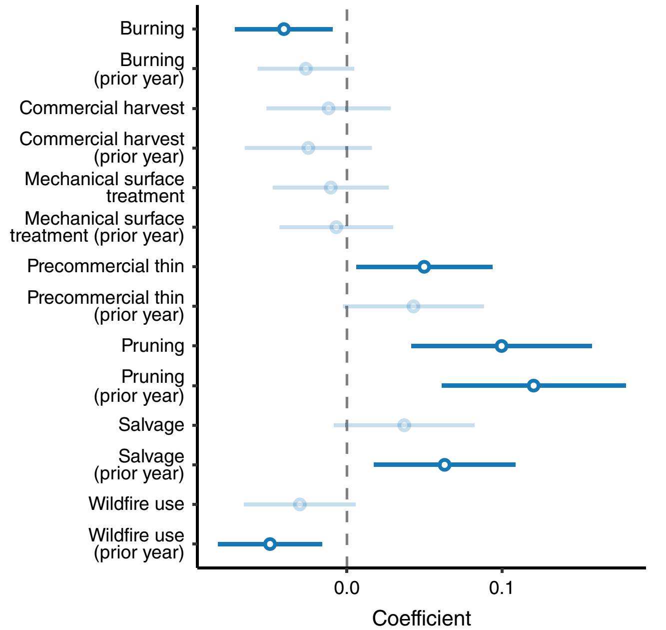

Fig. 3. The relationships between annual social media user-days and the seven fuel treatments occurring in the same or prior year. Circles show the coefficient estimate for each variable and lines indicate the 95% confidence interval. Points to the right of the dashed line indicate a positive relationship between area treated and visitation, while points to the left of the dashed line indicate a negative relationship. Insignificant variables are partially transparent. See Table 3 for all coefficient estimates included in the model.

programs and efforts (e.g. Oregon's Federal Forest Restoration Program and the USDA FS Wildfire Crisis Strategy) are aimed at expanding the investment in fuel treatments across large landscapes. In this study of one landscape fuel treatment program, we did not find any wholesale changes in visitation trends in project landscapes. Future research might consider the effects on recreation from other fuel treatment programs or the cumulative effects of multiple programs operating on one national forest or landscape.

Within CFLR projects, we found very modest influences on project area visitation from different amounts and types of fuel treatments. The slight negative influences of managed wildfire and prescribed burning on social media user-days that we observed are consistent with previous studies finding that people have a negative reaction to landscapes that have obvious signs of recent fire, such as dead trees and blackened or consumed vegetation (White *et al.* 2020; Tanner *et al.* 2022). Further, our findings about visitation after prescribed fire and managed wildfire are consistent with prior studies finding that immediate losses in visitation after wildfire can be modest (Brown *et al.* 2008; White *et al.* 2020).

Our findings of a slight positive influence on visitation from precommercial thinning to remove small trees and pruning are consistent with earlier research showing that people find open understories to be aesthetically pleasing and 'more suitable' for recreation, even in managed stands with a few small harvest openings in the canopy (Silvennoinen *et al.* 2002; Ribe 2009; Kearney and Bradley 2011; Tyrväinen *et al.* 2017). The positive perceptions of managed stands can disappear as harvest openings become larger and fewer trees are retained in the stand (Ribe 2009; Kearney and Bradley 2011; Tyrväinen *et al.* 2017) and that is consistent with our finding of no similar positive influence on social media user-days from the area undergoing commercial harvest. The suite of commercial harvest types used in the 2010s in the CFLR Program, in aggregate, do not appear to be having a significant influence on recreation use levels. We hypothesise that the positive influence associated with pre-commercial thinning is likely related to the number and size of trees removed in those treatments and that does not extend to more intensive commercial harvests. Ribe (2009) found that scenic beauty ratings by the public of forest stands in the Pacific Northwest of the US declined rapidly once the post-harvest stand basal area dropped below ~110 m^2/ha.

Our finding that salvage timber sales have a slight, positive effect on social media user-days is consistent with a prior finding by Ryan and Haman (2009) that people living near recent wildfires view salvage harvesting as making sites safer for post-wildfire recreation. Similarly, Tanner *et al.* (2022) found that potential recreationists view the presence of burned trees and other signs of recent fire as indications that the site is less safe for recreation. However, salvage harvest may also mark the point in time when portions of CFLR project areas previously closed to recreation because of natural disturbance are reopened to public access. Further, salvage harvest on USDA FS lands may also coincide with the beginning of the period when signs of the disturbance that are associated with a negative recreation response (White *et al.* 2020; Lorber *et al.* 2021; Tanner *et al.* 2022) are becoming less apparent. Further research at a diversity of sites with salvage harvest is needed to better understand relationships between salvage harvests and recreation.

We examine changes in total social media user-days, and that may mask unique responses of visitors engaged in different activities. For example, hikers and mountain bikers are known to have different responses to post-disturbance changes in forest conditions (Loomis *et al.* 2001). So, although both hikers and bikers post on the platforms included in this study and we find a slightly positive response in the number of social media posts in years with more pre-commercial thinning and pruning activities, it is possible that the increase we observe is driven by increases in one of those activities. The capacity of VGI to contribute to understanding of recreation behaviour will improve as we gain more ability to discern information about the type and character of recreational use, such as visitor activity or satisfaction.

This study considered recreation visitation for entire CFLR project landscapes but only portions of those landscapes receive fuel treatment. We did find statistically significant relationships between the magnitudes of some treatment types and recreation visits at the scale of the CFLR project, but it is possible that there are additional undetected effects of fuel treatment on recreation in the areas within or immediately adjacent to individual treatment units. However, because individual treatment units can be as small as just a few hectares, there is insufficient density of VGI to discern the magnitude of recreation visits at a similarly fine spatial unit of analysis. Sources of VGI data with potentially greater spatial density, such as mobile phone location data, may allow greater capacity to identify effects in future analyses.

Conclusion

As the extent and severity of wildfire have increased, policies and programs that promote removing vegetation that can increase the severity of wildfire and other natural disturbances have become more common across US Federal and state agencies. Here, we used a novel data source to understand how one such program – the USDA FS CFLR Program – influenced recreation use. In aggregate, landscapes designated under the CFLR Program did not have recreation use trends meaningfully different from other landscapes after the focused investment began. Within CFLR Program landscapes, we did find that some types of fuel reduction activities were associated with modest year-to-year changes in recreation use. The thinning of small, understorey trees (pre-commercial thinning) and removal of lower tree limbs (pruning) that could serve as fuel for wildfire to reach tree canopies had a slight, positive influence on year-to-year change in recreation visitation. Prescribed burning to remove brush and small trees had a slight negative influence on year-to-year change in recreation in the year of the burning but not the year after. Several of the CFLR landscapes experienced managed wildfire during our study years and those fires had a small negative influence on recreation use in the year after the fire. Finer-grained VGI visitation estimates are needed to better understand recreationists' responses to fuel treatment activities conducted over small areas or in different combinations. Further, research advances in our capacity to use VGI to describe the recreation experiences and visitor satisfaction would allow us to measure visitor reactions to fuel treatments.

Supplementary material

Supplementary material is available online.

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