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Applying Novel Visitation Models using Diverse Social Media to Understand Recreation Change after Wildfire and Site Closure

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ABSTRACT

Natural disturbances such as wildfires are increasing in severity and frequency. Although the ecological impacts of disturbance are well documented, we have limited understanding of how disturbances and associated management responses influence recreation use patterns. This reflects, in part, difficulty in quantifying recreation use across different land ownerships with inconsistent, or non-existent, recreation monitoring practices. In this study, we use visitation models based on social media to examine how recreation use changed after a wildfire and site closures in a large, mixed-ownership landscape. We find that wildfire and associated closures resulted in visitation loss to the recreation system as a whole and little site-to-site displacement within the system in the two years following the wildfire. Our study highlights the importance, when considering how wildfire and management may alter recreation use patterns, of considering the many factors that influence substitution behavior, including the relative locations of visitor origins, disturbances, and substitute sites.

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Modeling; natural disturbance; post-fire recreation; recreation site closure; social media

Introduction

The number of people engaging in nature-based outdoor recreation in the U.S. has increased with population growth (Outdoor Foundation 2019) and this trend is projected to continue in the coming decades (Askew and Bowker 2018). With more people engaging in recreation, visitation to trails, campgrounds, and developed recreation sites is increasing, especially on federal and state-managed lands (e.g., Smith, Miller, and Leung 2020; White et al. 2016). While recreation continues to increase, managers are also facing the challenge of more frequent and widespread natural disturbance (Winter et al. 2019). For example, over the last several decades, wildfires have increased in size, frequency, and severity in the western U.S. (Abatzoglou and Williams 2016; Jolly et al. 2015). Beyond wildfire, drought, flooding, wind events, and erosion can all alter the conditions at recreation sites or render them unavailable for use. Even disturbances over small areas can reduce the availability of trails, campgrounds, and other recreation sites, as they can require managers and owners to close sites, at least temporarily, to

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protect visitors and natural resources (e.g., Jedd et al. 2019). Such recreation site closures can cause significant lost benefit to recreationists (Sánchez, Baerenklau, and González-Cabán 2016). As these confounding effects of increasing use and disturbance ripple across the entire system, managers face the difficult situation of having to plan for future recreation use in the face of dynamic environmental and recreation conditions.

Natural disturbances and site closures can lead to changes in visitation as recreation use is displaced away from affected recreation sites and areas. This displacement can occur in response to the threat of potential disturbance (e.g., White, Bergerson, and Hinman 2020) as well as during (e.g., Borrie, McCool, and Whitmore 2006; Gellman, Walls, and Wibbenmeyer 2021; Jedd et al. 2019) and after (e.g., Brown et al. 2008; Schroeder and Schneider 2010) disturbance events. Our understanding of displacement and substitution patterns tends to focus on site-to-site displacement, but natural disturbances, which can alter conditions over relatively large areas and lead to closures of multiple recreation sites, have the potential to displace visitors across larger landscapes and recreation systems (e.g., Seekamp, Jurjonas, and Bitsura-Meszaros 2019).

As the context of recreation is evolving, so too are the tools available to measure recreation use and understand visitation patterns. New approaches for estimating visitation incorporate data from social media and other volunteered sources (Heikinheimo et al. 2017; Wood et al. 2013). Visitation models using social media alongside direct observations have been shown to provide reliable estimates of visitation to recreation resources of varying popularity, for different ownerships, and in varied settings (Wood et al. 2020). Social media also offers the potential to look back in time by hindcasting visitation in the recent past (Di Minin, Tenkanen, and Toivonen 2015) in landscapes lacking consistently collected, fine-grained recreation use data. Finally, social media can be leveraged to create consistent methods and common units for estimating visitation over landscapes comprised of multiple owners (e.g., different federal agencies, private lands) that employ different systems for measuring recreation use.

This study examines how visitors respond when a natural disturbance and resulting management closures dramatically alter the availability and condition of recreation opportunities within a recreation system. Our focus is the Columbia River Gorge (CRG) in Oregon and Washington, USA and the 2017 Eagle Creek Fire (ECF) and associated management closures. This recreation system is a collection of spatially-proximate recreation sites that serve as substitutes and complements to one another and share a set of visitors (Cesario 1969; Wetzstein 1982; Horne, Boxall, and Adamowicz 2005). We use a visitation model that incorporates data from social media to quantify changes in visitation patterns. Our objectives are to (1) understand how collective visitation to a recreation system changed following a large natural disturbance, (2) look for evidence of substitution to nearby recreation sites within the system following the disturbance, and (3) demonstrate the potential for visitation models that use social media to measure trends. To address these objectives, we ask three research questions:

1. Did the trend in visitation to all study sites collectively change after the ECF and did this pattern differ between the affected sites closed at some point and the unaffected sites that never closed?

2. After the ECF, did visitation to individual, unaffected sites increase above their pre-fire trends, indicating that visitors chose to substitute nearby sites when displaced from the closed sites?
3. Did visitation return to pre-closure trends at sites closed temporarily after the ECF?

Background

Recreation Choice and Substitution

Our understanding of how recreationists alter their behavior when a recreation site is undesirable or unavailable has been developed from recreation social science and economics (see Schneider 2007 and Bawa 2017 for reviews). Recreationists may alter their plans by electing to recreate at a different location, to recreate at a different time when the site is available or desirable, or to do something else entirely. Although the recreation literature provides a theoretical foundation for understanding how recreation behavior changes in the face of unavailable or undesirable recreation sites, the evolving and dynamic patterns in recreation use and increasing frequency and extent of natural disturbances, such as wildfire, offer new contexts for measuring how recreationists respond to changing availability of recreation opportunities.

The factors that influence whether, and where, potential visitors engage in substitution have received much attention in the literature. Some of the factors that reduce the willingness of a visitor to engage in spatial or activity substitution are a long distance between the visitor's home and destination (De Valck et al. 2016), visitor characteristics, such as lesser income and greater age (e.g., Seekamp, Jurjonas, and Bitsura-Meszaros 2019), greater specialization of the activity (e.g., fly fishing) or the recreationist (e.g., Oh, Sutton, and Sorice 2013; Orr and Schneider 2018), and a stronger connection to the original recreation destination (e.g., Graefe and Dawson 2013; Oh, Sutton, and Sorice 2013; Seekamp, Jurjonas, and Bitsura-Meszaros 2019). Sites that could serve as reasonable spatial substitutes are generally thought to be located within a similar travel distance (Graefe and Dawson 2013) of the original site and offer the potential for similar experiences (Fefer et al. 2021).

Wildfire and Recreation

In-situ studies in burned landscapes generally find that wildfires cause modest short-term reductions in recreation visits followed by a trend back to pre-fire visitation over relatively short periods of time (McCaffrey et al. 2013; White, Bergerson, and Hinman 2020), if sites are reopened after the fire is suppressed. Among those who visit burned areas after wildfires, satisfaction with the recreation experience remains high (e.g., Brown et al. 2008; Lorber et al. 2021; Love and Watson 1992), however, others may be choosing to not visit the burned location because they expect their recreation experience will be unsatisfactory. Although burned vegetation appears to have little influence on the activities visitors engage in (e.g., Brown et al. 2008; White, Bergerson, and Hinman 2020), the presence of a burned landscape does appear to influence visitor campsite and trail selection within areas that had a recent fire (e.g., Englin et al. 1999; Love and Watson 1992; Schroeder and Schneider 2010).

Volunteered Social Media

A growing number of studies over the last decade have explored the idea that information gleaned from social media is effective for measuring aspects of outdoor recreation, including the numbers, behaviors, and preferences of visitors (Di Minin, Tenkanen, and Toivonen 2015; Keeler et al. 2015; Ghermandi and Sinclair 2019; Teles da Mota and Pickering 2020; Wilkins, Wood, and Smith 2021; Wood et al. 2013). One common finding is that visitor counts are correlated with numbers of posts made about the same destinations on social media platforms, such as Flickr, Instagram, and Twitter (Fisher et al. 2018; Sessions et al. 2016; Tenkanen et al. 2017; Wood et al. 2013). Leveraging this finding, researchers have taken to using the density of geolocated social media that is shared from different locations to approximate variability in visitation over space and time to answer various questions, such as whether visitors prefer certain types of landscapes and environments (Keeler et al. 2015; Levin, Lechner, and Brown 2017). More recent research has shown how data from social media can be incorporated into models to estimate absolute numbers of visits to specific destinations (Wood et al. 2020). When used in concert with other information about visitation, social media can improve modeled estimates of visitation, even at unmonitored sites. Additionally, visitation models are improved by mixing multiple types of social media from different platforms which are popular with different user groups who participate in different recreational activities (Wood et al. 2020). These approaches that incorporate social media can be especially useful for monitoring recreation at times and locations where traditional monitoring efforts would be too costly or difficult (Fisher et al. 2018).

Recreation in the Columbia River Gorge

The CRG of Oregon and Washington stretches from east of Portland, Oregon more than 130 km upriver to the mouth of the Deschutes River. Recreation sites in the CRG are within day-trip distances for those living in the Portland metropolitan area. The CRG contains a wide variety of trails, developed recreation sites, campgrounds, waterfalls, undeveloped and roadless areas designated as wilderness under the 1964 Wilderness Act, and abundant opportunities for viewing nature. Several guidebooks focus specifically on outdoor recreation within the CRG. Recreation opportunities are managed by federal and state government agencies in addition to private timber companies (e.g., Weyerhauser Company), and nonprofit organizations (e.g., The Nature Conservancy). The recreation sites in the western end of the CRG are the most popular in the CRG recreation system. In 2014, the CRG was identified as one of the state's "7 Wonders" by Travel Oregon.

The tapestry of ownership in the CRG makes it difficult to develop comprehensive and comparable recreation use estimates at individual sites or for the CRG as a whole. This challenge arises because the metrics and methods for counting recreation visits differ between government agencies [e.g., United States Forest Service (USFS) versus

Oregon State Parks] and often recreation use estimates simply do not exist for other ownerships (e.g., private lands). The primary USFS lands within the CRG, the Columbia River Gorge National Scenic Area (CRGNSA), receive more than 2 M recreation visits each year and 1.2 M of these visits are in the western end of the CRG (White 2018). On the lands managed by the CRGNSA, the dominant recreation activities are hiking/walking (65% of visits) and viewing natural features (25% of visits) (USDA FS 2021). The majority of recreation visits to the CRGNSA (70%) involve recreation at just one site (USDA FS 2021).

In early September 2017 the ECF burned through forests and recreation sites in the western CRG. The human-caused fire began in the Eagle Creek Canyon and, driven by a strong afternoon wind, grew rapidly into nearby canyons and trail systems, trapping more than 100 hikers who had to be evacuated by rescue personnel. The ECF expanded west and east over the following weeks, ultimately growing to 19,773 ha before being subdued by wetter weather. Several of the most popular CRG recreation sites are within the fire footprint and suffered damage, such as destroyed trail bridges, debris-covered trail surfaces, and burned signage. In addition, expansive areas of standing dead trees and exposed rocks and boulders in the steep and windy landscape presented hazards to visitors. After the fire was controlled, sites within and on the periphery of the ECF footprint were closed as managers assessed conditions and mitigated hazards.

Methods

Study Sites

We selected 41 study sites that included both recreation sites directly affected by the ECF (and subsequently closed for some period) and unaffected sites that served as likely substitutes (Figure 1 and Table S1). For the unaffected potential substitutes we selected sites that offered non-motorized trail use or access to waterfalls, riparian areas, and undeveloped places for swimming and wading—opportunities like those provided at sites affected by the ECF. Site selection was informed by input from local USFS recreation managers, outdoor recreation guidebooks, and several highly publicized lists of recreation sites that were alternatives to the sites affected by the ECF.

We conceptualized sites as spatially distinct recreation destinations that a visitor might visit for a single day. The majority of these sites were single, non-motorized trails. However, four sites (Sites 6, 35, 40, and 41) were a collection of trails associated with distinct natural features and isolated from other study sites and one (Site 3) was a collection of undeveloped river and swimming access points along a county road. Of the 14 study sites directly affected by the ECF, eight were within the ECF footprint and six were adjacent. The six adjacent sites all reopened within approximately one year of the fire, while all sites within the burned area remained closed for the duration of our study: two years following the fire. We found the dates when each site reopened by looking at USFS official closure maps, looking for news articles about reopenings (using search terms such as “Eagle Creek Fire,” “closure,” “reopen,” and specific site names), and conversations with local recreation managers.

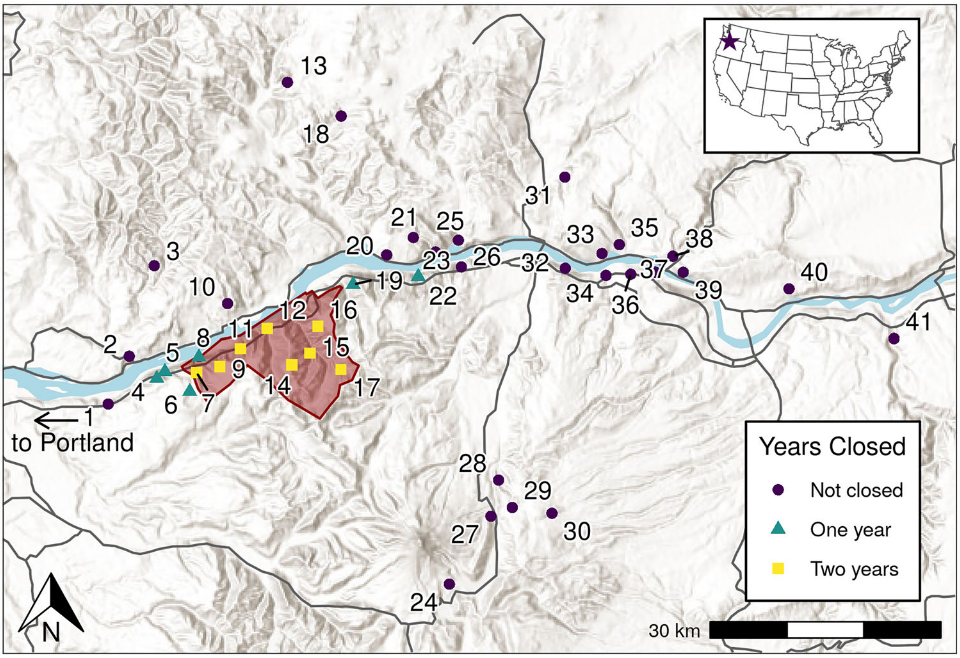

Figure 1. Location of study sites in the Columbia River Gorge, USA. The area burned in the Eagle Creek Fire is shown in red. Sites are numbered from west to east. Names and closure and reopening dates are in Table S1. The purple star on the reference map shows the location of the study area in the USA. The Columbia River forms the border between Washington (to the north) and Oregon (to the south) in this region.

Visitation Model

We estimated visitation by applying a statistical model that relied on measured variables that are known to be related to weekly visit counts. The model structure is described in detail in Wood et al. (2020). Briefly, the model quantifies the relationship between on-site counts of visits and the weather (precipitation), occurrence of holidays, seasonality (week of the year), and volume of social media shared by visitors to each site, in a multiple linear regression. The model was parameterized with data collected between 2016 and 2018 at 27 recreation sites in the Mount Baker-Snoqualmie National Forest (MBSNF), which is ~250 km north of the CRG. An earlier version of the visitation model was shown to perform well when used to predict on-the-ground visit counts outside MBSNF at unstudied locations in New Mexico (Model 2 in Wood et al. 2020).

For this study, the visitation model incorporated social media shared publicly on Flickr, Twitter, Instagram, and AllTrails to estimate the number of visits to each study site between September 2014 and August 2019. Flickr images were retrieved by querying the Flickr API in January 2020. Twitter posts were downloaded in real time from Twitter's streaming API. Instagram images were enumerated in April 2020, by first manually matching the names of Instagram locations to individual sites, then retrieving the owner and date of any photos posted to those locations during our study interval. Similarly, we retrieved the number of AllTrails reviews per user, date, and trailhead according to the website in April 2020. For every data source, we calculated the number of user-days (unique social media users who posted each day) per week, per site (Wood et al. 2013). We downloaded total daily precipitation data for the entire study period from the Bonneville Dam weather station in the Global Historical Climatology Network daily database (Menne et al. 2012).

Together, the combination of calendar, precipitation, and social media variables described more than 75% of the observed variability in weekly visitation at sites where the model was parameterized in the MBSNF (adjusted $R^2 = 0.76$; Table S2). User-days of AllTrails reviews, which were not included in the previously reported version of the visitation model, were a highly significant predictor in the model, improving the explanatory performance beyond what was previously reported (adjusted $R^2 = 0.63$ without the AllTrails predictor; Model 2 in Wood et al. 2020).

The model does not account for closures, and as such sometimes estimates a low level of visitation even if there are no corresponding social media data. For this study, we assumed that all closures were fully enforced and replaced model estimates during closed weeks with zeros. This assumption is supported by the fact that all closures were posted at trailheads, many trailheads were fenced closed, all closed sites were patrolled, and some had 24-h guards for months after the fire.

We aggregated the estimates of weekly visitation generated using the visitation model to estimate total visits annually to each site. Because we were interested in the patterns in recreational use before and after the ECF, we chose to define our years based on the date of ignition on September 2, 2017. Thus, the year immediately preceding the fire was defined as September 2016–August 2017. We excluded from our analysis the week following ignition, due to a large number of social media posts which we suspect were about the fire itself, rather than a reflection of visitation. In this way, we estimated five years of visitation per site: Year -3 (September 2014–August 2015), Year -2 (September 2015–August 2016), and Year -1 (September 2016–August 2017) all preceded the fire, while Year 1 (September 2017–August 2018), and Year 2 (September 2018–August 2019) followed the ECF.

Sites reopened in phases, with two sites reopening in October 2017 (six weeks after the fire), two sites reopening in June 2018 (ten months after the fire), and four sites reopening in November 2018 (13 months after the fire). All eight sites within the ECF footprint remained closed at the end of our study period, two years after the fire (Table S1). While reopening dates did not coincide perfectly with our definition of years post-fire, we considered the two sites which reopened within six weeks to have been open for Years 1 and 2, and the six sites which reopened in 2018 to have been closed for Year 1, but open in Year 2.

Trend Models

To judge whether recreation use at individual sites changed following the fire, we first estimated what visitation would have been without the disturbance and closures caused by the fire. The number of outdoor recreation participants has been steadily increasing across the country over the last decade (Outdoor Foundation 2019), and this general increase was apparent in our visitation estimates for many of our sites. As a result, we chose to use the three years of pre-fire visitation to calculate linear trends reflecting the change in visitation over those years.

We created three distinct models based on the level of estimated visitation in the year preceding the fire. Eleven sites were classified as being high visitation (more than 20,000 visits in Year -1), ten sites as medium visitation (between 4000 and 20,000 visits), and 20 sites as low visitation (fewer than 4000 visits). For each set of sites, we created a weighted linear regression. Year -3 was given half the weight of Years -2 and -1, owing to lower confidence in our estimates from that year based on more limited social media. Each model included fixed effects for year and site, while the medium and high visitation models also included an interaction between year and site, allowing for individual site trends over time. The interaction term was not significant in the low visitation model, so it was excluded.

We used the linear trend models to predict visitation in Years 1 and 2, assuming growth in visitation would have continued at the same rates if the fire had not occurred in the system, and we calculated 95% prediction intervals for each of the sites in Years 1 and 2. Next, we compared these predictions with our best approximation of actual visitation in Years 1 and 2 according to our visitation model (described above). We interpreted any site-year in which the visitation estimate fell outside of the prediction interval from the trend model as an instance of visitation being significantly different ($\alpha = 0.05$) than what would have been expected if the fire did not occur.

Results

Trend Models

We found that visitation was increasing in the years preceding the fire at our high-use sites (adjusted $R^2 = 0.88$). The rate of this increase varied by site, ranging from ∼6600 additional visits per year at Site 15 (Eagle Creek) up to more than 29,000 additional visits each year at Site 7 (Oneonta Gorge). Likewise, visitation was increasing at the medium-use sites (adjusted $R^2 = 0.92$), ranging from 800 additional visits per year at Site 33 (Coyote Wall) to more than 6000 additional visits per year at Site 27 (Tamanawas Falls). Our low-use model did not produce evidence of increasing visitation in the years preceding the fire across all low-use sites, nor was it able to distinguish individual trend lines for the sites. However, it did show significant differences in the number of visits to individual sites, allowing us to predict the number of visits to those sites in Years 1 and 2 (adjusted $R^2 = 0.59$).

Collective Trends

Our first research question focused on understanding collective change in visitation to the study sites. Total visits to the study sites declined precipitously in Year 1 (2017–2018) immediately following the ECF (Figure 2). Visitation in Year 1 was 60% of that observed in Year -1. Visitation rebounded in Year 2 (2018–2019) but remained below the visitation levels observed in the year preceding the fire. The loss in visitation post-ECF was counter to the steep increasing trend in visitation in the years prior to the ECF.

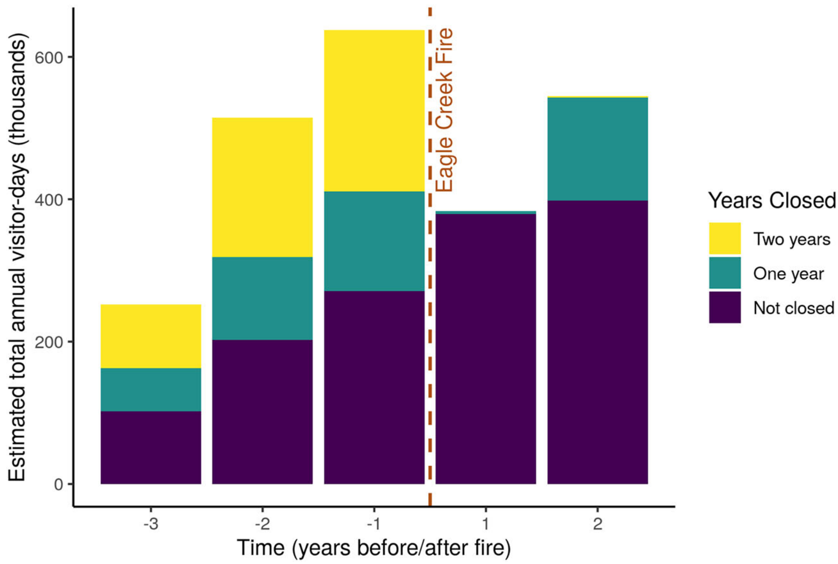

Figure 2. Estimates of total visitation summed across 41 study sites in the Columbia River Gorge created using the visitation model. The height of the bars indicates the total number of estimated visitor-days to the entire recreation system per year relative to the Eagle Creek Fire (ECF). Year -3 is Sept 2014–Aug 2015, Year -2 is Sept 2015–Aug 2016, etc. Bar color indicates the number of years that a site was closed following the ECF (Table S1). The teal ("One year") segment in Year 1 reflects visitation to two sites that reopened ten months after the fire, and were considered "closed" in that year for our analysis.

The collective loss in visitation to our study sites was driven by lost visits at those sites closed after the ECF. We predicted 481,000 visits would have occurred in Year 1 and 581,000 in Year 2 at the sites closed post-ECF. Instead, we observed 4000 visits to those sites reopening in June 2018 in Year 1 (a loss of 477,000 visits), and 147,000 to sites that were reopened by Year 2 (a loss of 434,000 visits). Visitation at study sites that remained open post-ECF continued to grow in the years following the ECF. However, the collective increase in visits to the never-closed sites in the years immediately after the ECF paled in comparison to the visits lost from closed sites.

Site-Level Patterns

Our second research question focused on assessing whether visitation at individual sites, after the ECF, differed from expected visitation based on pre-fire trends. Visitation in Years 1 and 2 was not significantly different than what we expected from pre-ECF trends at our high-use study sites that remained open after the ECF. Of those high-use sites, only Sites 10 (Beacon Rock) and 21 (Dog Mountain/Augspurger Mountain) experienced visitation in Year 1 or 2 that was meaningfully different from the trendline (Figure 3). However, visitation estimates for both sites were still within the prediction interval. The departure from the visitation trendline at Site 21 coincided with implementation of a ticketed entry on that trail system in 2019.

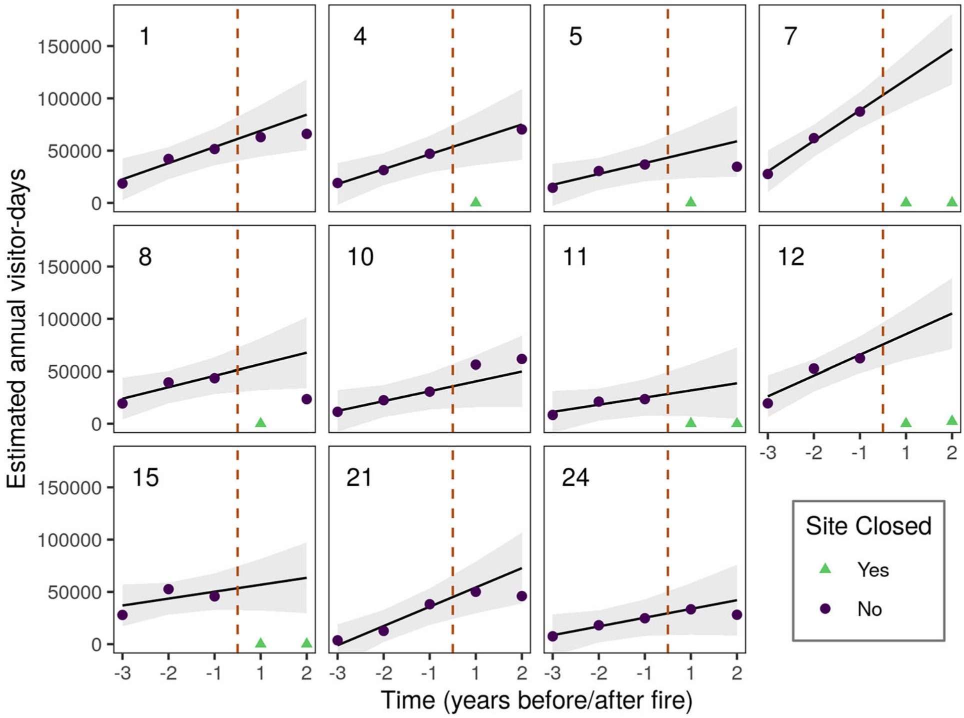

Figure 3. Site-level estimates of annual visitor-days to high-use sites. Points show annual estimated visitation to each site created using the visitation model, colored by whether or not the site was closed during that year. Trend lines display the high-use trend over time based on Years -3, -2, and -1, and projected forward into Years 1 and 2. The gray ribbon indicates a 95% prediction interval, while the dashed red line indicates the time of the ECF. Site numbers are in the upper left corner of each panel and are defined in Table S1.

With the exception of Sites 21 and 24, the 11 high-use sites included in our study were located in the western CRG. Four of these (Sites 7, 11, 12, and 15) were within the ECF footprint and did not reopen in Years 1 and 2 and three (Sites 4, 5, and 8) were adjacent and closed for 13 months. At Sites 4 and 5, visitation rebounded to the prediction interval in Year 2, but visitation to Site 8 (Horsetail Falls) was significantly less than predicted by the pre-fire trend.

Visitation to some medium-use sites differed significantly from the expected trend post-ECF. Visits to Site 37 (Tom McCall) were significantly greater than our trend prediction in Years 1 and 2 and the growth between those two years was substantial (Figure 4). Visitation to Site 13 (Falls Creek Falls) was significantly greater than predicted in Year 1 but within the prediction interval in Year 2. In contrast, at Site 33 (Coyote Wall), a sharp increase in visitation in Year 2 moved visitation above our prediction interval. At Site 29 (Surveyor's Ridge/Cook's Meadow), visitation in Year 2 was significantly lower than the trendline. Site 6 (Larch Mountain) was closed in the first year after the ECF but reopened in Year 2. Like the pattern observed for two of the three temporarily closed high-use sites, visitation at Larch Mountain rebounded to our prediction interval once the site was reopened.

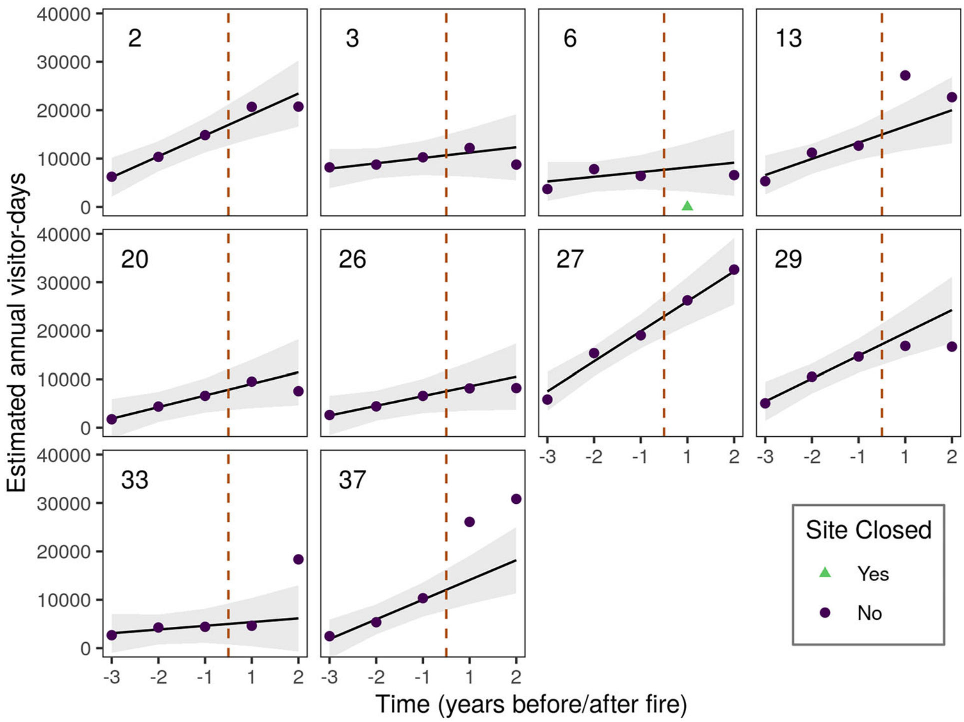

Figure 4. Site-level estimates of annual visitor-days to medium-use sites. Points show annual estimated visitation to each site created using the visitation model, colored by whether or not the site was closed during that year. Trend lines display the medium-use trend over time based on Years -3, -2, and -1, and projected forward into Years 1 and 2. The gray ribbon indicates a 95% prediction interval, while the dashed red line indicates the time of the ECF. Site numbers are in the upper left corner of each panel and are defined in Table S1.

At low-use sites, observed visitation in Years 1 and 2 was within our prediction interval for almost all sites that were open after the ECF. Two sites had visitation in Years 1 and 2 that were significantly above (Site 25, Spirit Falls) or below (Site 34, Mosier Plateau) our predicted trend (Figure 5). Two sites—Site 18 (Panther Creek Falls) and Site 35 (Catherine Creek)—had visitation in Year 1 that was significantly less than the expected trend but returned to the prediction interval in Year 2. Departures from our predicted trendline, although not the prediction interval, happened more often for the low-use sites than the other sites included in our study. This is likely due to the relatively lower confidence of our visitation model in predicting visitation at sites with fewer social media posts, leading to higher variability in the year-to-year estimates of use.

Discussion

In the face of wildfire and associated management closures of the most popular recreation sites, our study system exhibited (1) a reversal in its recent trend of consistent visitation increases for the system as a whole, (2) little evidence of displacement of recreation visits to the remaining open sites, (3) a change in the spatial distribution of

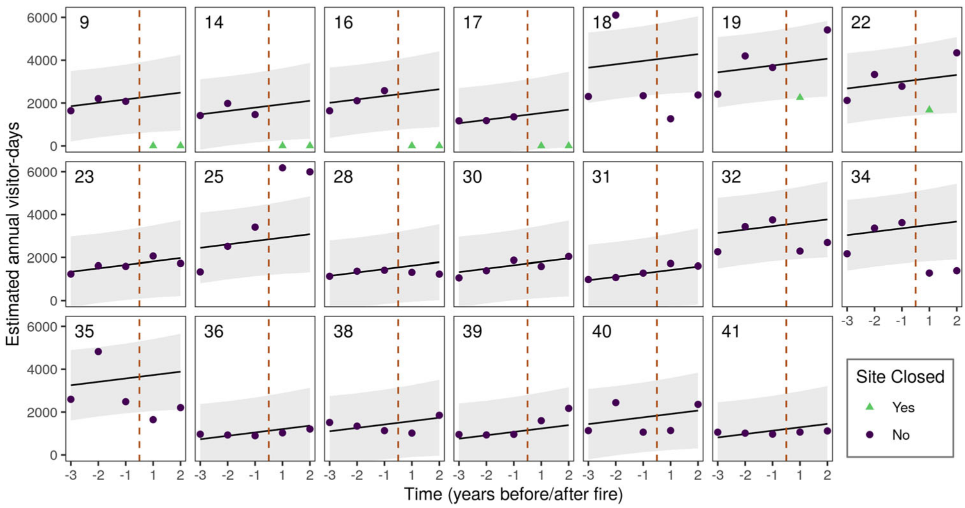

Figure 5. Site-level estimates of annual visitor-days to low-use sites. Points show annual estimated visitation to each site created using the visitation model, colored by whether or not the site was closed during that year. Trend lines display the low-use trend over time based on Years -3, -2, and -1, and projected forward into Years 1 and 2. The gray ribbon indicates a 95% prediction interval, while the dashed red line indicates the time of the ECF. Site numbers are in the upper left corner of each panel and are defined in Table S1. Sites 19 and 22 each reopened in June 2018, roughly ten months after the ECF, so visitation in Year 1 reflects the two months in which they were open.

visits, and (4) the beginnings of a trend back to pre-disturbance conditions as closures were rescinded.

We expected displacement of visits to other sites within the study system, based on the recreation substitution literature, pre-ECF statements by visitors that they would engage in spatial substitution if needed (USDA FS 2021), and the highly publicized lists of alternative recreation sites within the CRG. However, we found little evidence of such displacement. In general, visitation at sites that were open after the ECF continued their pattern of year-to-year increases in visitation, consistent with pre-ECF trends. Just four of the never-closed sites saw visitation in either Years 1 or 2 that was significantly above the expected trend.

We think the lack of displacement within our study system highlights the potential importance of the relative locations of visitor origins, recreation system sites, and the natural disturbance, in addition to the distance to substitutes (e.g., Graefe and Dawson 2013; De Valck et al. 2016) and degree of substitutability of alternative sites (e.g., Lo 1991; Fefer et al. 2021). Our CRG study system spreads west and east for 130 km, with the ECF and associated closures located between the most-populated visitor origins to the west and the greatest number of potential substitute sites in the east. For those residing to the west of the CRG who would otherwise recreate in the western CRG, the ECF and management closures necessitated longer travel distances to reach most of the open CRG recreation sites. Prior studies of USFS CRG visitors found that 73% stated an intention to do their same activity at another recreation site if their intended CRG destination was unavailable (USDA FS 2021). Based on our findings, it appears that, when faced with the longer travel distances to reach unaffected CRG sites, visitors who did engage in spatial substitution elected to recreate outside the CRG system. The unwillingness to travel a greater distance to recreate in the CRG was likely magnified if visitors viewed alternate CRG sites as imperfect substitutes or closed sites as important secondary, or complementary, sites that they would otherwise incorporate in a CRG visit (Lo 1991). The notion that visitors in different origins relative to the CRG system would be more likely to substitute away from the CRG system is consistent with Seekamp, Jurjonas, and Bitsura-Meszaros' (2019) finding that visitor residence was a key factor in willingness to engage in spatial substitution away from the coastal recreation system in their study.

In addition to the loss in total visits discussed above, the wildfire and associated closures of sites in the west end of our study system caused a spatial redistribution of visits within the system. Prior to the ECF, the western CRG sites (those affected by the ECF) accounted for the vast majority of recreation visits in the system. After the ECF, this pattern reversed and the sites unaffected by the ECF (in the central and eastern portions of the system) accounted for nearly all visitation in Year 1 and the bulk of visitation in Year 2. Such rapid redistribution in relative visitation may have implications for managers who have allocated infrastructure (such as interpretive signs) and field personnel based on historic patterns. Changing distributions of use may have additional implications for communities and businesses if, for instance, the concentrations of recreation users suddenly shift to different communities around recreation sites or traffic patterns change as access routes become more or less congested.

Our third research question centered on whether visitation returned to pre-fire trends at those sites temporarily closed by the ECF. Although none of our study sites within the footprint of the ECF reopened during our study, several sites reopened on the fire's periphery. The landscape-wide tree mortality that resulted from the ECF was readily visible from the reopened sites and visitors could hike into some of the dispersed recreation areas within the ECF footprint (although those areas were not the primary destinations). Visitation rebounded to pre-fire trends at all but one (Site 8) of the six periphery sites that reopened after the ECF. Access to Site 8 (Horsetail Falls), although allowed for 11 months in Year 2, was limited to a relatively short (1.4 km) two-waterfall loop. Ultimately, we found little evidence that proximity to a burned area resulted in a reduction in visitation. Our results complement prior studies that have observed that losses in visitation after wildfire are transient (Brown et al. 2008; Kim and Jakus 2019; McCaffrey et al. 2013; White, Bergerson, and Hinman 2020).

Social Media and Visitation Models

This study of pre- and post-fire recreation was possible because we developed and applied methods using social media to hindcast recreation visits to discrete locations spanning a large landscape. This approach was particularly useful in the CRG where recreation opportunities are managed by a diverse set of federal and state government agencies as well as nonprofit organizations who collectively do not maintain consistent, statistically reliable estimates of visitation. Accurately estimating visitation for the variety of recreation activities and settings in the CRG required us to blend information from several social media platforms (Twitter, Instagram, Flickr, AllTrails), each of which is popular with different user groups and in different periods over the past five years.

The application of novel approaches that use social media data to measure recreation use was fundamental to our ability to characterize change within this recreation system in response to disturbance and management action. Beyond a simple lack of existing recreation use data, the lack of pre-knowledge about the timing of the disturbance in this system precluded our ability to implement data collection that could have helped us measure pre- and post-event conditions. The types of novel approaches we use in this study hold promise for addressing emerging research questions about recreation behavior in response to disturbances and related management actions associated with global climate change.

Management Implications

The changes in visitation in our system after the ECF appeared to be driven primarily by management closures of sites affected by the ECF. As we plan for more frequent and severe natural disturbances and a greater number of recreationists, managers and policy-makers might prioritize developing tools and processes that help to minimize the time that recreation sites must be closed after natural disturbance. Based on the observed patterns at our study sites, and the findings of others, managers may expect rapid returns in visitation once sites closed after natural disturbance are reopened, even if the natural resource conditions around those sites have been altered.

Managers and researchers who are interested in using social media to measure and understand visitation patterns will likely benefit from approaches that incorporate data from multiple platforms. For characterizing trends over time, we found it useful to combine data from AllTrails, a newer platform that is increasing in content, with Flickr, a well-established platform that offers content dating back over a decade. However, even when using multiple platforms, there may not always be enough social media content to make reliable inferences about visitation patterns or visitor behavior at sites with relatively few visits. In this study, we found that sites with less than about 6000 visits a year (16 visits per day, on average) often lacked a sufficient volume of social media to develop reliable visit estimates.

Limitations

Our findings should be considered in the context of the limitations of our approach. Our analysis depends on the transferability of the visitation model, which assumes that the relationships between visitation, social media posting rates, seasonality, and precipitation are consistent between the MBSNF and the CRG. This assumption is supported by the findings reported in Wood et al. (2020) which demonstrate the transferability of the model from MBSNF to sites in northern New Mexico. Because our goal was to understand changes in the immediate aftermath of the ECF, we focused on the initial years post disturbance and did not attempt to describe long-term changes in visitation. Additionally, our interest in this research is related to understanding aggregate behavior across visitors. As such, our methods were not designed to allow us to analyze the influence of the ECF on individual visitor behavior, perceptions, or motivations. Finally, our focus solely on the CRG system precludes our ability to compare recreation trends in the CRG system after the ECF to trends in adjacent recreation systems.

Conclusion

Our understanding of how natural disturbances, and associated management actions, lead to changes in recreation behavior has not kept pace with the increasing frequency and severity of those disturbances. This study, and others, have found that disturbance and related recreation site closures can lead to dramatic changes in recreation system use patterns, at least in the short term. Additional research is needed to understand the longevity of recreation behavior changes post-disturbance and management action and how changes in one recreation system can influence conditions in other recreation systems. Novel methods, such as those used here, clearly have a role in improving our understanding in this area given their ability to accommodate backward looking research questions and landscapes with mixed ownership and inconsistent recreation monitoring data.

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