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Research Note

Analysis of fire frequency on the Talladega National Forest, USA, 1998-2018

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Abstract. Fire is an essential ecological process and management tool for many forested landscapes, particularly the pine (*Pinus* spp.) forests of the southern USA. Within the Talladega National Forest in Alabama, where restoration and maintenance of pine ecosystems is a priority, fire frequency (both wild and prescribed) was assessed using a geographical process applied to a fire history database. Two methods for assessing fire frequency were employed: (1) a simple method that utilised the entire range of years acknowledged in the database and (2) a conservative method that was applied only the date of the first and last fires recorded at each location. Analyses were further separated by (a) method of mean fire return interval calculation (weighted by area or Weibull) and (b) fire season interval with analyses conducted on growing season and dormant season fires. Analyses of fire frequency for national forest planning purposes may help determine whether a prescribed fire program mimics ecological and historical fire frequencies and meets intended objectives. The estimated fire return interval was between ~5 and 6.5 years using common, straightforward (simple) methods. About one-third of the forest receives no fire management and about half of the balance has sufficiently managed fuels.

Additional keywords: pine ecosystems, prescribed fire, temperate forests, wildland fire

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Introduction

From the period of time just before European colonisation through the implementation of United States (US) federal fire management in the early 20th century, vast expanses of southern US forests were subjected to periodic fires that were initiated by both nature (lightning) and native Americans (Waldrop and Goodrick 2018). Therefore, fire ecologically shaped the character and composition of many southern pine (*Pinus* spp.) forests (Waldrop *et al.* 1992; Noss 2018; Stambaugh *et al.* 2018). The character and composition of southern pine forests changed dramatically in the 20th century as a result of many factors, such as the US federal fire management policy of fire suppression and exclusion, human population growth, land conversion and climate change. In recent years, federal fire management policies and strategies in southern pine forests have shifted to include an increased use of prescribed fire (Melvin 2018). The US Forest Service conducts prescribed fires on 10% of managed lands annually (~500 000 hectares (ha) of 5 million ha) to meet a variety of management objectives, including wildlife habitat management, wildfire hazard reduction and ecosystem restoration (US Forest Service 2012). These activities are guided by forest plan objectives that seek to restore ecological communities (US Forest Service 2004) and are further supported by the ideals and desires of regional restoration initiatives that focus on specific forest ecosystems (e.g. Longleaf Partnership Council 2019).

The fire history of a landscape is often described by the frequency and intensity of fires occurring at specific places across a landscape; this knowledge of landscape fire history helps land managers understand how vegetation types have developed and changed over time (McBride 1983). The observed fire frequency for a landscape is often communicated as the fire return interval, or fire interval. The fire interval is generally considered to be the average time that has passed between successive fires during a specific time period (Dugan and Baker 2014). Fire recurrence influences the probability of plant survival and the time available for individual plants to mature (Díaz-Delgado *et al.* 2004); therefore, the fire interval can potentially inform land managers of ecological pathways for forests. The fire interval also influences the type and amount of forest floor fuels potentially available and consumed during prescribed and wildland fires (Gavazzi and McNulty 2014).

One objective of the present research was to develop a new geospatial tool to assess fire frequency, fuel accumulation and seasonality of fires using monthly dates of fire initiation. A second objective was to apply the tool to a fire history database developed by the Talladega National Forest in Alabama, which includes the spatial locations of fires dating back over 20 years. From a managerial perspective, the fire frequency analysis tool could be used to further educate the public, to help plan future fire activities and to help assess prescribed fire programs to determine whether forest management goals are being achieved. This information, for example, can help prescribed fire managers evaluate current temporal fire patterns and facilitate a comparison with historical and ecological norms. This information can also be of value in assessing fuel loads across the landscape, integrating wildfires into prescribed fire programs and in allocating and protecting resources through strategic decision-making processes.

Materials and methods

Study area

The Talladega National Forest (approximately centred at 33.51°N, 85.80°W) is located in north-eastern Alabama, situated within the Piedmont and Ridge and Valley ecoregions of the USA. The Talladega National Forest is located in the Talladega Mountains and is managed by the US Forest Service. This area is characterised by a humid subtropical climate with hot and humid summers and mild winters. Annual precipitation in this area is ~1260 mm. A modest degree of forest management activity began on the national forest, beginning in 1936, when it was established and expanded under authority of the *Weeks Act* (Chapter 186, 36 Stat 961) and other proclamations (US Forest Service Lands and Realty Management Staff 2012). Fire suppression was implemented through the late 1980s when prescribed fire management began to be used to restore ecosystems and manage fuel loads. Over this period of time, forests on many upland sites were harvested and planted with loblolly pine (*Pinus taeda* L.). Today, the national forest is composed of 93 694 ha of land and contains a mosaic of vegetation types that include broadleaf hardwood, natural pine and planted pine forests. About 52% of the national forest is composed of stands dominated by four coniferous tree species: loblolly pine, longleaf pine (*P. palustris* Mill.), shortleaf pine (*P. echinata* Mill.), and Virginia pine (*P. virginiana* Mill.).

Management of the Talladega National Forest currently involves ecological systems for which historical fire frequency norms have been estimated and attempts to manage forest fuel loads from the ecological conditions, fuel load and smoke potential perspectives. The Forest Service is mandated through a forest plan (US Forest Service 2004) and supporting legislation to provide for multiple resource values, which include the restoration of native ecosystems and endangered/threatened flora and fauna native. In addition, the Forest Service is responsible for mitigating the threat of wildfire on this forest. Dendrochronology, accumulation of fuel loads, historic community assessment and fire frequency assessments (Guyette *et al.* 2012) all indicate that the past four centuries of forest development are a good indication of how these systems persisted across the landscape. This information suggests the metrics needed to monitor restoration activities of a portion of the ecosystem. With the exception of areas around the wildland–urban interface, active fire management is viewed as a prerequisite for achieving desired ecological conditions.

An analysis of witness trees (documented trees at corners of sections and townships during the implementation of the Public Land Survey System) from four townships in the Talladega Mountains describes a forest dominated by pine and fire-dependent hardwood communities in the uplands during the 1830s (Shankman and Wills 1995). From dendrochronological records that extend from 1547 to 2005, fire scars indicate that the fire return interval was 2.7–3.2 years during the period 1660–1831 in the Talladega Mountains, 2.6 years during the period 1832–1940 and then fire events were absent from the record from 1940s to 1990s (Bale 2009; Stambaugh *et al.* 2018). Studies of post-fire event fuel beds indicate that ~58% of the potential total litter accumulation was achieved within 2 years of a fire and greater than 90% within 3 years (Bale 2009). In addition, 92–97% of the fire events occurred during the dormant season (Bale 2009), which pairs temporally with climatic fall drought (September to November) and dry winter (January to March) frontal systems. These lines of evidence describe a landscape that experienced low-intensity, high-frequency fire events that shaped the pine and hard hardwood forest composition and grassland understory structure. After the US Forest Service acquired ownership of the lands that now define the Talladega National Forest, it implemented 50–60 years of fire suppression policy that continues today on about one-third of the landscape.

Analysis methods

The approach we utilised to assess fire history involved computing area frequency, rather than point frequency, where fire occurrence is assessed at the scale of a landscape (Díaz-Delgado *et al.* 2004). Here, the history of recent fires (prescribed and wildfire ignitions) is known for the landscape during the study period and is described using a geographic information system (GIS) database of fire polygons maintained by the Talladega National Forest (i.e. in ArcGIS). To accommodate these analyses, the Fire Frequency Analysis Tool 2.0 was developed in Python and enabled as a tool through ArcToolbox. Although many attributes of fires are useful in documenting fire activity, in this case the only necessary attribute of the polygon features was the initiation date of each fire. The tool assesses the range of the fire initiation dates and uses these to determine the number of months between successive fires. The tool reduces the multipart polygon data that may be present in the database to a single set of polygon features that describe individual fires that have occurred across the landscape. This monthly manner of estimating fire return intervals is a major enhancement on the Stober and Holden (2014) method, which used annual calculations. The tool computes the time since last fire, which is based on fire history database records (Enright *et al.* 2011; Huffman *et al.* 2012; Kelly *et al.* 2017) and produces frequency and recency statistics describing both growing season and dormant season fires. We assumed the period between April 1 and September 30 defines the growing season in this analysis.

The mean fire return interval (MFI) is also computed to illustrate the temporal characteristics of fire occurrence (Guyette *et al.* 2014). MFI is estimated by determining the number of months between successive fires at specific locations on the landscape. These are then converted to an annual estimate for the entire landscape considered. At the landscape scale, we also computed a weighted average MFI using the size of each fire event polygon as the basis. For a given ecosystem, the MFI is a critical metric that can act as a proxy for understory condition, overstory composition, duff accumulation and fuel load development. The MFI can infer an effect of a fire management program on the communities managed. Fire can be used to shift the composition of a community's flora and fauna. In the use of a MFI, fire effects can be evaluated through the ecological differences that emerge due to persistent and cumulative effects of fire management.

The tool we developed also computes the mean fire rotation (MFR) or the amount of time required to burn an area the size of landscape being considered (Díaz-Delgado *et al.* 2004; Huffman *et al.* 2015). As well as the MFR, a Weibull MFI (WMFI) is derived and both are used to characterise fire frequency (Grissino-Mayer 1999; Engbring *et al.* 2008; Cerano-Paredes *et al.* 2015). Analogous to the mean of a normal distribution (Engbring *et al.* 2008), and perhaps consistent with other fire frequency analyses, the WMFI is a function of both the scale and shape parameters associated with the Weibull distribution of fire event timing (Moritz *et al.* 2009). The tool also characterises fire frequency using a simple median fire interval. We decided against using a Poisson Process Model to determine the probability of fire occurrence mainly because most of the fire ignitions on the national forest are prescribed fires and not randomly distributed through time or space, as is typically assumed (Díaz-Delgado *et al.* 2004).

For all analyses, a straightforward (simple) method was used to determine fire frequency statistics using the range of dates of fires in the database (244 months) and the number of fires that occurred at each place on the landscape. Mean landscape fire frequency was developed using fires as sample observations regardless of fire size. The variance, standard deviation and standard error of these landscape estimates were also computed. However, a conservative method for determining fire frequency was also developed, using only the range of dates of fire initiations for each fire event polygon.

$$\text{Conservative fire frequency} = \left(\frac{\text{number of months between first and last fire}}{\text{numbers of fires} - 1}\right)$$

In this case, it might be assumed that the first and last fires represent the ends of a range of time (rather than the extent of dates in the database); therefore, to divide the range of time by two fires (rather than one fire) underestimated fire frequency. The conservative method is another major enhancement of the Stober and Holden (2014) method. With the exception of the MFR, MFI, weighted average MFI, WMFI and the median fire interval are all assessed using both simple and conservative methods. Where appropriate, the frequency of dormant and growing season fires was also assessed using both the simple and conservative methods.

Results

Over a 244-month period, between January 1998 and May 2018, 2093 fires occurred on the Talladega National Forest, ranging in size from less than 1 ha to 1307 ha. Approximately 13.1% of the national forest experienced a fire each year, on average, suggesting that the MFR would be ~7.6 years even though some areas of the national forest may be unsuitable for supporting a prescribed fire given local conditions. The average size fire was 119 ha and even though the national forest contains only 93 694 ha of land, recorded fires covered 249 792 ha, indicating that several areas were burned more than once during the 20-year study period. With respect to wildfires, 616 events covering 13 187 ha were recorded over the study period, averaging 21 ha in size. The largest wildfire was 1280 ha. Of the known causes of wildfire ignition, arson and other direct human action was most prevalent (74.1% by area), followed by lightning (8.1%). With respect to prescribed fires, 1469 events covering 236 641 ha were recorded, averaging 161 ha in size. The largest prescribed fire was 1307 ha. The primary objective for most prescribed fires was fuel reduction (85.4% by area), followed by wildlife habitat maintenance (8.3%). The categorisation of eight fires was uncertain. On average, two-thirds of prescribed fires occurred during the dormant season from January through March. During some years, the growing season fires accounted for as much as 50% of the fire program activity, but rarely more. Over the period of analysis, 67% of the national forest experienced at least one fire (Fig. 1*a*) and 33.0% experienced no fires at all. Of the areas that had not experienced a fire, 46.8% were characterised by a dominant forest type other than pine; 42.1% had a dominant forest type consisting of an oak (*Quercus*) species.

Using the simple method for determining fire frequency, the MFI across the landscape was estimated to be 5.69 years (Table 1), the median fire frequency was estimated to be 5.08 years and the WMFI was estimated to be 6.46 years. The spatial location of the fires was concentrated in areas where restoration activities, including timber management, were focused on endangered species management (Fig. 1*b*). The weighted MFI was estimated to be 5.36 years, about half-way between the median fire frequency and the MFI. The distribution of fires in the areas that were burned was positively skewed, to the right, as may be seen in the frequency distribution in Table 2. Using the simple method for determining fire frequency, half of the burned areas had a MFI of 4 years or less and two-thirds of the burned areas had a MFI of 6 years or less (Fig. 1*c*).

Using the conservative method for determining fire frequency, the fire frequency estimates were longer (Table 1). The MFI across the landscape was estimated to be 9.06 years, the median fire frequency was estimated to be 6.75 years and the WMFI was estimated to be 10.17 years. Again, the spatial location of fires was concentrated in areas where current restoration goals focused on wildlife habitat development. The frequency of fires in these areas was lower when using the simple method for estimating the fire return interval (Fig. 1*d*). The weighted MFI using the conservative method was estimated to be 8.24 years, which was again between the median fire frequency and the MFI, but closer to the MFI in value. Given the MFI classes we chose, the distribution of fires had two peaks, one at 2–4 years and the other at 8+ years, as may be seen in the frequency distribution in Table 2. Using the conservative method for determining fire frequency, half of the burned areas had a MFI of 6 years or less and two-thirds of the burned areas had a MFI of 8 years or less.

When we employed the simple method to determine fire frequency using only growing season fires, the MFI was estimated to be 8.58 years and the weighted MFI was 8.76 years. However, the median fire frequency was estimated to be 10.17 years. The spatial locations of growing season fires seemed relatively evenly distributed across the forest. However, the distribution of growing season MFI for individual fires was negatively skewed, to the left (Table 3). Using the simple method for determining fire frequency of growing season fires, two-thirds of the areas experiencing a growing season fire had a MFI of 8 years or more. Using the conservative method for determining fire frequency, the MFI for growing season fires

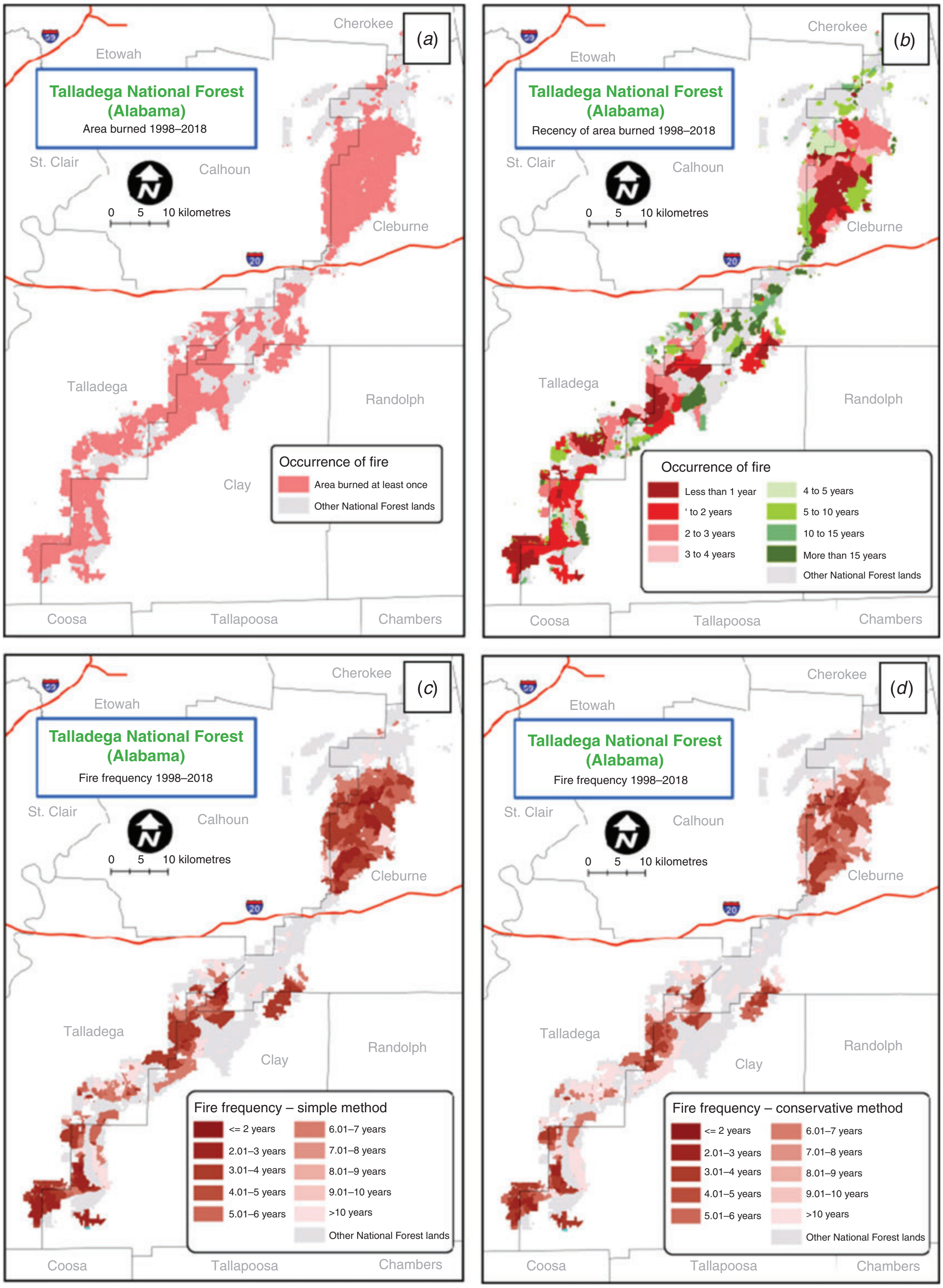

Fig. 1. Talladega National Forest (*a*) area burned between 1998 and 2018, (*b*) recency of fires, prescribed and wild, through May 2018, (*c*) mean fire return interval using simple method, 1998–2018 and (*d*) mean fire return interval using conservative method, 1998–2018.

was estimated to be 15.93 years and the weighted MFI was 16.39 years. The median fire frequency was estimated to be 20.33 years. The distribution of fires was again negatively skewed, to the left. Using the conservative method for determining fire frequency of growing season fires, nearly 90% of the areas experiencing a growing fire had a MFI of 8 years or more.

Table 1. Fire return intervals for all areas burned on the Talladega National Forest, 1998–2018
MFI, mean fire interval

	Fire return interval (years)
Simple method	
MFI	5.69
Median fire interval	5.08
Weibull MFI	6.46
Weighted MFI	5.36
Conservative method	
MFI	9.06
Median fire interval	6.75
Weibull MFI	10.17
Weighted MFI	8.24
Mean fire rotation	7.63

Table 2. Frequency and cumulative frequency of all areas burned on the Talladega National Forest, 1998–2018, using the simple and conservative methods for determining mean fire interval (MFI)

	MFI (years)	Area (ha)	Cumulative area (ha)	Percent of total area burned (%)	Cumulative percent of total area burned (%)
Simple method	< 2.01	253	253	0.5	0.5
	2.01–4.0	26 005	26 258	49.5	50.0
	4.01–6.0	9355	35 613	17.8	67.8
	6.01–8.0	8425	44 037	16.0	83.8
	> 8.0	8516	52 554	16.2	100.0
Conservative method	< 2.01	13	13	0.0	0.0
	2.01–4.0	14 930	14 943	28.4	28.4
	4.01–6.0	11 314	26 528	21.5	50.0
	6.01–8.0	9355	35 613	17.8	67.8
	> 8.0	16 941	52 554	32.2	100.0

When we employed the simple method to determine fire frequency using only dormant season fires, the MFI was estimated to be 6.77 years and the weighted MFI was 6.74 years. The median fire frequency was estimated to be 10.17 years. The distribution of growing season MFI was negatively skewed, to the left, as may be seen in the frequency distribution in Table 3. However, using the simple method for determining fire frequency of dormant season fires, ~71% of the areas experiencing a dormant season fire had a MFI of 8 years or less. There appeared to be about the same amount of dormant season fires in three MFI classes (4.01–6 years, 6.01–8 years and 8+ years). The locations of dormant season fires were concentrated in three focal areas of restoration of the national forest. Using the conservative method for determining fire frequency, the MFI for dormant season fires was estimated to be 11.34 years and the weighted MFI was 11.27 years. However, as with growing season fires, the median fire frequency was estimated to be 20.33 years. As with other distributions, the distribution of fires was negatively skewed, to the left. Using the conservative method for determining fire frequency of dormant season fires, over 56% of the areas experiencing a fire had a MFI of 8 years or more.

Table 3. Frequency and cumulative frequency of growing and dormant season fires on the Talladega National Forest, 1998–2018, using the simple method for determining mean fire interval (MFI)

	MFI (years)	Area (ha)	Cumulative area (ha)	Percent of total area burned (%)	Cumulative percent of total area burned (%)
Growing season	< 2.01	0	0	0.0	0.0
	2.01–4.0	731	731	3.4	3.4
	4.01–6.0	1648	2379	7.7	11.1
	6.01–8.0	4993	7372	23.3	34.4
	> 8.0	14049	21 422	65.6	100.0
Dormant season	< 2.01	0	0	0.0	0.0
	2.01–4.0	7940	7940	16.4	16.4
	4.01–6.0	13192	21 132	27.3	43.7
	6.01–8.0	13190	32 322	27.3	71.1
	> 8.0	13984	48 306	28.9	100.0

Discussion

Historical fire frequency norms are just reference points that are ecologically correlated with forest fuel loads and the floral communities that national forest management is tasked with restoring, per the forest plan (US Forest Service 2004) and regional restoration initiatives (e.g. Longleaf Partnership Council 2019). These ecological goals require knowledge of the frequency of prescribed fire events so that programs can be assessed and directed. The tool that was developed in this study allows identification of fuel-rich environments as well as frequently burned areas that have reduced fuel loads and represent desired future conditions. Regular fire management is a prerequisite to obtaining the desired ecological condition in this forest and arguably everywhere fire management plays a role in wildlands management. Therefore, fire frequency and the seasonality of fire management are likely the best indicators of fuel load and condition of ecosystems in the south-eastern USA. The metrics used to describe fire frequency on the Talladega National Forest, whether using the simple or conservative method, indicate a longer return interval between successive fires than historical norms. These forest communities, which currently consist of ~33% of the area under management on the Talladega National Forest, are moving away from, rather than towards, desired future conditions. A portion of the areas have recurrent wildfire events and could be incorporated into the prescribed fire program to mitigate and dampen the effect and occurrence of wildfire in these areas and expand the area under prescribed fire management.

Landowners need information and tools to evaluate whether management programs are achieving the desired objectives (Bigelow *et al.* 2018). The Talladega National Forest is fortunate to have historical evidence of fire return intervals to illustrate the fire dependence and frequency of the forest ecosystem. For example, although Bale *et al.* (2008) found through dendrochronology and analysis of fuel bed loads that a 2–3-year fire return interval was common over the four previous centuries until interruption in the 1940s when the land became a national forest, our results suggest only about half of the land area burned had a MFI of 4 years or less.

Often when conducting these types of analyses, the simple method for determining fire intervals (i.e. MFI) is reported, by dividing the time range of the data considered by the number of fires that had occurred on the landscape being investigated. When the time range record is long enough, and when the sample size of fires is large, the resulting MFI may be appropriately estimated. Although the Talladega National Forest fire databases are relatively rich with data, the time frame of fires is relatively short. Therefore, we developed a conservative method for estimating MFI that, when at least two fires had occurred for a part of the landscape, the time range is defined by the earliest and latest fires. In an assessment of nearly 1000 burned areas, the conservative method always produced a fire return interval longer than with the simple method. Therefore, in some management circumstances, both estimates may be necessary to express reasonable fire return intervals for the landscape. The simple method might be used to describe conditions of a landscape that has experienced many fires over time. The conservative estimate might be used in fire-suppressed environments where few fires have been conducted or when the time frame is relatively short. The longer the time frame, the more likely that estimates from the conservative method will converge with estimates from the simple method. Further, because the new tool uses a monthly time frame rather than an annual time frame (as in Stober and Holden 2014), it results in more appropriate estimates when the time frame is relatively short.

The tool described here can be used to assess current fire management programs and contrasts that with ecological norms derived through fuel levels or other metrics of fire history or management. The tool estimates frequency of fire management during both growing and dormant seasons, as the season of fire can be used to both understand fire behaviour as well as the effects on forest communities (Waldrop *et al.* 2016). The new calculations conducted by month also better represent the frequency of areas burned, allow a more accurate assessment of fuel loads and thus facilitate prioritisation of areas for treatment. In many areas across the Talladega National Forest, forest fuel loads often need to be reduced in order to best utilise growing season fires. If one considers the hazardous fuel reduction and restoration of fire-dependent communities as separate, non-overlapping goals of national forest management, the rate of prescribed fire activity over the past 20 years represents ~41% of the forest plan's target (US Forest Service 2004). Because dormant season fires can be used to promote the use of subsequent growing season fires, particularly to reduce fuel loads, the national forest is preparing for an expanded growing season prescribed fire program. However, growing season fires are challenged by operational windows that require optimal atmospheric conditions. Therefore, some areas may experience repeated dormant season prescribed fires to further reduce fuel loads or simply because the window of opportunity during the growing season is too narrow.

The US Forest Service leadership is generally risk averse by nature (Kolden 2019). Utilising prescribed fire to reduce hazards and restore fire maintained landscapes (Schultz and Moseley 2019) needs to be viewed as a progressive management tool for achieving management targets, otherwise wildfires may be inevitable and result in conditions far from management targets. Policies likely need to be changed to address this reality. In the near-term, a pyrodiverse management philosophy will likely be utilised on the Talladega National Forest due to limited resources. However, the seasonal application of fires is important because of the different effects fires may have on the flora and fauna of the ecosystem when conducted at different times of the year. In order to adequately apply prescribed fire to landscapes, policy needs to incentivise leadership on the role of fire on the landscapes being managed, to streamline the protracted process to receive credentialing to conduct prescribed fires, to develop better smoke management strategies, to allow timely hiring of qualified employees and to create a culture that incentivises productive high-functioning teams. The Forest Service could also place an emphasis on populating corporate databases with fire events so the liability of forest fuels can be accurately assessed and areas for specific fuel reduction treatments more easily identified.

Conclusions

The scale and capacity of the fire program seems inadequate at this time for approaching the historical range of fire intervals estimated for the Talladega National Forest and for addressing the flora and fauna dependent on these frequent disturbances. This has been noted for US national forests as a whole, as funding for forest restoration and prescribed fire does not seem adequate to address the scope of the problem (Schultz and Moseley 2019). A lack of prescribed fire in some areas of the Talladega National Forest landscape could result in delayed efforts aimed at improving or maintaining longleaf and shortleaf pine ecosystems. A forest manager can use outcomes from analyses described here to understand where different treatments have been used, and to determine where there may be reduced fuel loads (based on a more frequent fire return interval) so that they may be able to conduct more growing season prescribed fires. This information can allow one to comprehensively evaluate, monitor and change a fire program over time.

Conflicts of interest

The authors declare no conflicts of interest.

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