

BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL,
PRINCIPAL BENCH, NEW DELHI

I N D E X

IN

RESPONSE AFFIDAVIT

(On behalf of the Respondents No. 2, 3, 4 & 5)

(In Compliance to the Hon'ble Tribunal's Order dated 21.10.2024)

IN

O.A. No. 425 OF 2023

Deepika Khari

.....Applicant

Versus

State of U. P. & Ors.

.....Respondents

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Dated: /05/2025



Deepak Bora
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BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL,
PRINCIPAL BENCH, NEW DELHI

RESPONSE AFFIDAVIT

(On behalf of the Respondents No. 2, 3, 4 & 5)

(In Compliance to the Hon'ble Tribunal's Order dated 17.02.2025)

IN

O.A. No. 425 OF 2023

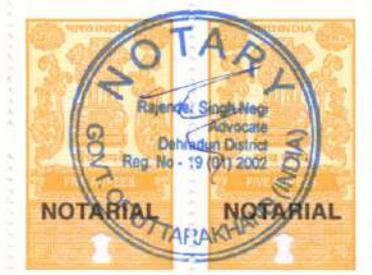
Deepika Khari

.....Applicant

Versus

State of U. P. & Ors.

.....Respondents



Affidavit of Dr. Dhananjai Mohan
(Male), aged about 59 years, S/o
Sh. S. S. Rajput, presently posted as
Principal Chief Conservator of
Forests (HoFF), Uttarakhand,
Dehradun.

(Deponent)

I, the above-named deponent, do hereby solemnly affirm and state on
as of:

1. That the deponent is presently posted as Principal Chief Conservator of Forests (HoFF), Uttarakhand, Dehradun. This Hon'ble Tribunal has arrayed the Principal Chief Conservator of Forests/HoFF, Uttarakhand

as Respondent No.3 and as such he is fully conversant with the facts of the case.

2. That on 17.02.2025, after the course of hearing in the present matter, this Hon'ble Tribunal was pleased to pass certain directions and direct the respondents to file response to the queries asked by this Hon'ble Tribunal in the present matter. The relevant paras of the said Order dated 17.02.2025 are being quoted here for kind perusal of this Hon'ble Tribunal:

"6. Response dated 20.11.2024 has been filed by Additional PCCF (Fire and Disaster Management), Dehradun and response affidavit dated 06.01.2025 has been filed by MoEF&CC.

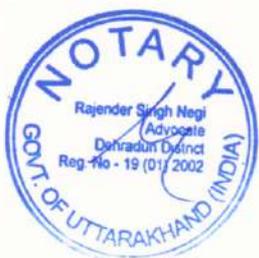
7. *The substantial environmental questions which arise in the present case may be noticed as under:-*

(i) Whether controlled fire is the only method of preventing/controlling fire in the forest or there is any other alternative method;

(ii) Whether the method of controlled fire adopted for preventing/controlling fire in the forest is supported by any scientific study regarding efficacy of the above said method; and

(iii) Whether the said method has been approved by MoEF&CC as a remedial measure for preventing/controlling forest fires.

8. *In view of the nature, magnitude and importance of substantial environmental questions involved in the present case, we consider it appropriate to widen the scope of the present proceedings so that the substantial environmental questions involved can be looked into by the*



[Handwritten Signature]

concerned authorities and appropriate remedial measures can be taken.

9. *Appropriate responses with reference to the substantial environmental questions noticed above may be filed by PCCF, Uttarakhand and also by MoEF&CC”.*

3. That in compliance to the above direction passed by this Hon'ble Tribunal, a comprehensive report with respect to the queries asked by this Hon'ble Tribunal has been prepared which is being annexed herewith as ANNEXURE-1.

4. That the deponent undertakes to comply the directions to be passed by this Hon'ble Tribunal in the present matter.

I, the above named deponent, do hereby verify that the contents of Para nos. 1-2, 4 of this affidavit are true to my personal knowledge, those of Para nos. 3 of this affidavit are based on records, those of Para nos. of this affidavit are as per the legal advice received and those of Para nos. of this affidavit are as per the information received which all I believe to be true. That no part of this affidavit is false and nothing material has been concealed.

DEPONENT

So help me God



I, Avnish Gupta, Legal Assistant, Forest Department, Uttarakhand, Dehradun, do hereby identify the deponent who has produced the records of the case before me and I am satisfied that he is the same person as alleged.


IDENTIFIER

Solemnly affirmed before me today, the 2nd day of May, 2025 at 8:00 am/pm by the deponent who has been identified by the aforesaid person.

I have satisfied myself by examining the deponent that he has understood the contents of this affidavit, which have been read over and explained to him.


OATH COMMISSIONER/NOTARY





This Affidavit is Sworn before me by
Shri/Smt. Dhanraj Malan
who is identified by Shri A. Gupta
at Dehradun on 2/5/25


Rajender Singh Negi
Advocate & Notary, Dehradun

**Response to the environmental questions asked by the Hon'ble NGT vide its order dated 17.02.2025
in Deepika Khari versus State of UP and Ors.**

Reference is cited to the above-mentioned order dated 17.02.2025. In this regard, in para number 07 in the order, referred to as above, following substantial environmental questions have been raised which are provided below: -

- I) Whether controlled fire is the only method of preventing/controlling fire in the forest or there is any alternative method;
- II) Whether, the method of controlled fire adopted for preventing/controlling fire in the forest is supported by any scientific study regarding efficacy of the above method; and
- III) Whether the said method has been approved by MoEF&CC as a remedial measure for preventing/controlling forest fires.

In compliance to the para no. 9 of the above-mentioned order, appropriate responses with reference to the above-mentioned questions are provided as under: -

- I) Whether controlled fire is the only method of preventing/controlling fire in the forest or there is any alternative method;

Response: -

The control burning is a traditional method of reducing the fuel load in the forest thereby reducing the chances of large fires in the warmer months. This method has been prescribed as a management tool and finds place as prescriptions in the management/working plans for the forest divisions in the State of Uttarakhand. The control burning is carried out with an objective to reduce the leaf litter available in the forest areas and is normally carried out before the onset of the fire season. However, during the fire season also, in a strictly regulated manner, as necessitated by leaf fall period, it is carried out as a fire drill especially along the roads, around the periphery of the plantations, etc. in order to prevent any chance of forest fire.

No, the control burning/controlled fire is not the only preventive method for controlling forest fires. Besides this, there are other methods also viz. clearing the fallen leaf litter manually along the roads and around the periphery of the raised plantations before the fire season. However, this requires much more resources owing to higher manual labour and time involved.

- II) Whether the method of controlled fire adopted for preventing/controlling fire in the forest is supported by any scientific study regarding efficacy of the above method;

Response: -

The method of controlled fire/control/prescribed burning adopted for controlling fire in the forest is supported by various scientific studies globally, many of which have been carried out to assess its efficacy.

The relevant and key parts of the few conducted scientific studies are provided as under: -

- a)- **Crystal A. Kolden, 2019. "We're Not Doing Enough Prescribed Fire in the Western United States to Mitigate Wildfire Risk" by Department of Forest, Rangeland, and Fire Sciences, University of Idaho Fire 2019, 2, 30; doi:10.3390/fire2020030** - Prescribed fire not only reduces the biomass available to burn in a subsequent uncontrolled wildfire, it also supports carbon sequestration, facilitates ecological resilience, and is critical in restoring ecological function in regions where decades of fire exclusion pushed fire-adapted ecosystems outside their historic range of variability and degraded such function.
- b)- **Marcos Francos and Xavier Úbeda, 2021. "Prescribed fire management" Environmental Science & Health 2021, 21:100250-** Prescribed fire is often used for environmental and land management, and **controlled burning** has proved a good tool to manage large forest areas in cases where economic resources are limited, being economically beneficial and feasible for land management.
- c)- **W. Lachlan McCaw, 2013. "Managing Forest fuels using prescribed fire – A perspective from southern Australia" Forest Ecology and Management 294 (2013) 217–224** - Prescribed fire is increasingly recognized as also playing an important role in mitigating undesirable effects of high intensity fires on environmental values including soil, water and biodiversity.
- d)- **M. P. North, S. L. Stephens, B. M. Collins, J. K. Agee, G. Aplet, J. F. Franklin, P. Z. Fulé, 2015 "Reform Forest fire management" SCIENCE 18 September 2015 • VOL 349 ISSUE 6254** - Fire can also be used to reduce fuels either intentionally (prescribed burning) or opportunistically (letting a natural ignition burn as "managed wildfire") under moderate weather conditions.
- e)- **Paulo M. Fernandes and Herminio S. Botelho, 2003 "A review of prescribed burning effectiveness in fire hazard" International journal of Wildland Fire, 2003, 12.** Wildfire hazard abatement is one of the major reasons to use prescribed burning. The best result of prescribed fire application is likely to be attained in heterogeneous landscapes.
- f)- **S. Little, J. P. Allen and E. B. Moore "Controlled Burning as a Dual Purpose Tool of Forest Management in New Jersey's Pine Region"-** Controlled burning does not eliminate the need for organized fire suppression, but supplements it. At the same time, this type of burning greatly favors reproduction of pines instead of that of the less desirable hardwoods.
- g)- **Susan J. Prichard, David L. Peterson, and Kyle Jacobson, 2010. "Fuel treatments reduce the severity of wildfire effects in dry mixed conifer forest, Washington, USA". Can. J For. Res. 40:1615-1626.-** This study provides strong quantitative evidence that thinning alone does not reduce wildfire severity but that thinning followed by prescribed burning is effective at mitigating wildfire severity in dry western forests.

The complete research articles of the above scientific studies are annexed as **Annexure No. 1 (1.1 to 1.7)**

Moreover, the control burning has been prescribed as a management tool in the working/management plans of the forest divisions that are prepared for 10-year period. The areas for control burning which are sensitive to forest fires are taken up in accordance with the working/management plans.

As an example, the prescriptions regarding control burning provided in the working plans of Dehradun and Garhwal Forest divisions are provided as an **Annexure No. 2 (2.1 to 2.2)**.

III) Whether the method has been approved by MoEF&CC as a remedial measure for preventing/ controlling Forest fires.

Response: -

Control burning has been prescribed as a management tool in the working/management plans of the forest divisions that are prepared for 10-year period and are duly approved by MoEF&CC.

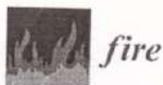
Moreover, the **National Action Plan on forest fire issued by MoEF&CC** in 2018 includes the provision of control burning and the concerned prescriptions provided there-in are mentioned as under: -

Para 6.4 Control Burning: -

Control burning may be necessary in some places for preventing spread of fire. The following actions are recommended to improve the consistent performance and effectiveness of control burning wherever necessary:

- I. Prioritization of areas for control burning as part of fire risk zonation analysis.*
- II. Monitoring of performance of control burning at the Circle level and integration of monitoring data into a database maintained by the SFDs;*
- III. Timely release of funds for control burning prior to the onset of the peak fire season and the provision of advance/ad-hoc release as needed;*
- IV. Development of state-specific guidelines for control and prescribe burns to be notified and revised as may be necessary.*

This National Action Plan on forest fire issued by MoEF&CC is annexed as **Annexure No. 3**.



Article

We're Not Doing Enough Prescribed Fire in the Western United States to Mitigate Wildfire Risk

Crystal A. Kolden

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Abstract: Prescribed fire is one of the most widely advocated management practices for reducing wildfire hazard and has a long and rich tradition rooted in indigenous and local ecological knowledge. The scientific literature has repeatedly reported that prescribed fire is often the most effective means of achieving such goals by reducing fuels and wildfire hazard and restoring ecological function to fire-adapted ecosystems in the United States (US) following a century of fire exclusion. This has translated into calls from scientists and policy experts for more prescribed fire, particularly in the Western US, where fire activity has escalated in recent decades. The annual extent of prescribed burning in the Western US remained stable or decreased from 1998 to 2018, while 70% of all prescribed fire was completed primarily by non-federal entities in the Southeastern US. The Bureau of Indian Affairs (BIA) was the only federal agency to substantially increase prescribed fire use, potentially associated with increased tribal self-governance. This suggests that the best available science is not being adopted into management practices, thereby further compounding the fire deficit in the Western US and the potential for more wildfire disasters.

Keywords: indigenous burning; traditional ecological knowledge; wildland fire; controlled burning; prescribed burning; Cerro Grande

1. Introduction

Recent disastrous and fatal wildfires across the United States (US) have yielded renewed calls to reduce the wildfire hazard [1–4]. One of the primary hazard reduction strategies identified in the scientific literature is prescribed burning—the intentional ignition of controlled fire, which is also referred to as prescribed fire or controlled burning in the US [5]. Prescribed fire not only reduces the biomass available to burn in a subsequent uncontrolled wildfire [5–7], it also supports carbon sequestration [8,9], facilitates ecological resilience [10–12], and is critical in restoring ecological function in regions where decades of fire exclusion pushed fire-adapted ecosystems outside their historic range of variability and degraded such function [12–14]. As anthropogenic ignitions and climate change have enabled the expansion of the fire season and larger and more disastrous wildfires [15–18], many of the recent high-profile scientific syntheses and perspectives have specifically advocated for increased use of prescribed fire [1–4,19,20]. Similarly, the US National Cohesive Wildland Fire Management Strategy (hereafter, Cohesive Strategy)—a planning effort stemming from the 2009 FLAME Act—specifically identified prescribed fire as the most cost-effective solution over the largest potential area of the US, as compared to managed wildfire and non-fire vegetation treatment [21]. Both the best available science and guiding policy documents in the US support more prescribed fire, but there has been limited assessment of whether this is translating to practice.

The intentional use of fire across landscapes has a long history in the US that is rooted in both the widespread indigenous burning practices of many North American tribes and the use of fire as a land-clearing tool by settlers prior to the 20th century [22]. At the onset of the 20th century,

perceptions about intentional burning underwent a fundamental shift, particularly in the Western US, where large wildfires threatened lives and timber resources and cultivated modern US wildfire policies [23]. Science-based efforts to restore fire to Southeastern forests were underway by the 1930s, while prescribed fires and natural wildfire were reintroduced into Western national parks and wilderness areas in the 1960s [22]. In parallel, American Indian tribes have sought to reintroduce fire, both to reclaim sovereignty through self-governance of tribal lands and to maintain important tribal cultural components [24–26]. There is also recognition that considerable extant traditional ecological knowledge (TEK) surrounding fire and indigenous controlled burning practices persists in native communities throughout the US [25]. This indigenous knowledge is a rich potential source of information and strategies for implementing more prescribed fire through collaborative partnerships with tribes, but remains underutilized [25–27].

As has been widely documented, prescribed fire is not without drawbacks. Prescribed fires produce smoke, which can violate air quality regulations and has negative impacts to human health [28–30]. Prescribed fires infrequently escape to become wildfires. Perhaps the most notable of such incidents was the 2000 Cerro Grande Fire, which began in early May as a prescribed fire at Bandelier National Monument in New Mexico but escaped to become a 19,000 ha wildfire. The Cerro Grande Fire consumed 235 homes [29] and subsequently shut down nearly all federal prescribed burning in the US for several months. These potential negative effects translate to social perceptions that provide considerable barriers to the widespread use of prescribed fire [30]. A considerable challenge for science has been to accurately assess the trade-offs of prescribed fire versus wildfire, particularly as wildfires occur relatively infrequently for a given location and indirect or secondary wildfire effects are difficult to quantify.

A Web of Science search of refereed literature of the terms “prescribed fire”, “controlled burning”, and “prescribed burning” demonstrates that over the past century, 4275 total refereed indexed papers were published that addressed prescribed fire in the US (Figure 1), with only one prior to 1972. There is a significant positive trend during this period as the literature expands around prescribed fire and controlled burning. It covers a broad range of topics, but the literature is overwhelmingly associated with Environmental Sciences and Ecology (85%), with only a small proportion affiliated with relevant disciplines such as Business/Economics (6%), Public Health (5%), Water Resources (4%), Engineering (3%), and Social Sciences (1%). Notably, while earlier literature focused on prescribed fire as a tool to restore fire excluded from so-called “fire-prone” forests (i.e., historically high-frequency and low-severity fire forests), more recent literature has investigated the use of controlled burning across a range of ecosystems to reduce hazardous fuels, not just forests considered prone to fire.

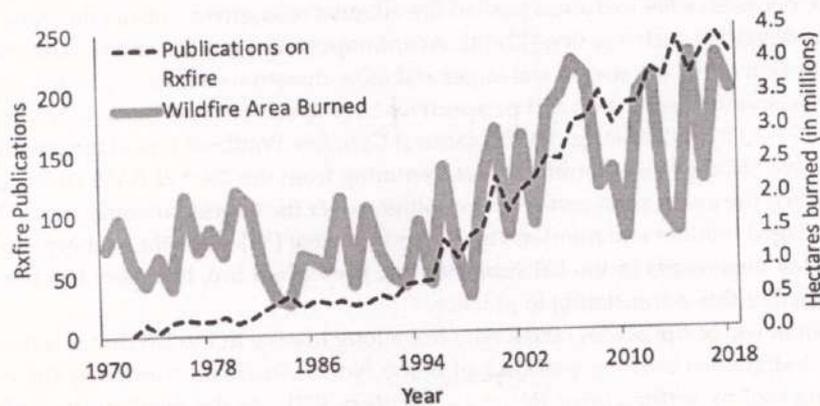


Figure 1. Annual publications on prescribed fire (dashed black line) and annual area burned (red solid line) for the United States (US), 1970 to 2018.

This trend towards increased understanding of prescribed fire should theoretically support its increased application, and such application is sorely needed. In the US Pacific Northwest, Haugo et al. [31] reported that for the 31-year period between 1984 and 2015, wildfire burned just 1.6 mill ha across a subset of forests in Washington and Oregon. This total was an order of magnitude less than the 15–21 mill ha expected under historical fire regimes and in the absence of fire suppression and exclusion. This deficit included 7–10 mill ha of the type of low-severity fire that prescribed burning can replace or be used to restore ecological function [31]. Other more general studies have similarly reported widespread wildfire deficits across western US forests [32]. To date, however, there has been little assessment of changes in US prescribed fire use in response to increased understanding of both its effects and the broader fire deficit.

My primary objective was to assess whether the US federal land management agencies are translating the best available science and current national fire policies into the increased use of prescribed fire. I also sought to assess regional and agency differences in order to understand which regions and agencies are increasing their prescribed fire accomplishments, as would be expected given the increased emphasis in both the scientific literature and policy. The adoption of increased prescribed fire use may be a key indicator of sociocultural acceptance of fire, which is a critical first step in effectively reducing wildfire vulnerability [20].

2. Methods

I evaluated trends in the application of prescribed fire in the US from the National Interagency Fire Center (NIFC) Situation Report (SIT Report) Archives and Historical Wildland Fire Summaries (available at www.nifc.gov). The annual Historical Wildland Fire Summary reports published by NIFC list both wildfire and prescribed fire accomplishments for each state stratified by federal agency (or non-federal entities), and date back to 2002 (but do not include prescribed fire in 2018). The SIT Report Archive includes the daily (during peak US fire activity) to weekly (during low fire activity) reports of large fires, cumulative wildland fires and area burned, and cumulative prescribed fires and area burned from 1998 to present. I utilized the cumulative prescribed fire data included in the last published SIT Report for each calendar year for the temporal analysis, and the Historical Wildland Fire Summaries to explore state-level trends.

For each Geographic Area (as defined by NIFC), more commonly referred to as a Geographic Area Coordination Center (GACC) region, I calculated a Spearman's Rho (years versus area) to assess trends, the annual mean accomplishment for a given GACC (ha/year), the trend or slope (mean change in ha/year from 1998 to 2018), the relative trend as a percent based on the mean accomplishment of a GACC (slope/mean accomplishment * 100), the percent of the US total 1998–2018, and the percent of the US trend 1998–2018. As GACCs vary widely by size and the amount of land managed by various agencies (Table S1), I also calculated an area weighting for the annual mean accomplishment by GACC and agency to normalize by area. Similarly, I calculated these metrics for each agency class. The five primary federal land management agencies that manage wildfire are each an individual class (i.e., the Bureau of Indian Affairs (BIA), the Bureau of Land Management (BLM), the Fish and Wildlife Service (FWS), the National Park Service (NPS), and the US Forest Service (USFS)), while a sixth class denoted as "State/Other" (ST/OT) includes any entity reporting that does not fall under the five primary federal agencies. This includes both other federal agencies that accomplish substantial prescribed fire, such as the Department of Defense (DOD) on military installations, the Department of Energy (DOE), the Bureau of Reclamation (BOR), as well as both state and even some private/non-profit entities where state agencies complete and report accomplishments (Table S1). I did not limit the analysis to any one ecosystem or fire regime type (e.g., historically fire-prone forests). As noted previously, more recent literature and management policies such as the Cohesive Strategy do not limit prescribed fire as a hazard reduction tool to any ecosystem.

The SIT Report Archive is not perfectly equivalent to the annual Historical Summaries because the data were not yet assessed for quality control, and also because the last report of the year was often published prior to December 31 (so additional accomplishments may have been reported in the last few days of the year). However, because the Archive dates back to 1998, it provides four additional years of data in a relatively short time series. The annual prescribed fire totals for the SIT Report final report of the year and the official totals provided in the Historical Wildland Fire Summaries are nearly equivalent for the 2002–2017 overlap period ($r^2 = 0.9992$). It should be noted that while these data can include prescribed burns conducted by private entities working with agency partners, they largely exclude the type of broad-scale private lands burning that occurs in grasslands and rangelands (e.g., the annual pasture burns across the Flint Hills region of Eastern Kansas).

3. Results

As recorded in the National Interagency Fire Center Daily Situation Reports, fire agencies completed a reported 23 million hectares of prescribed fire (averaging just over 1 mill ha per year) over the period 1998 to 2018, and annual totals increased by an average of 61,678 ha (mean 5% annual increase) per year (Table 1, Figure 2). However, 70% of all prescribed fire and 98% of the increase over time was observed in the Southeastern US Geographic Area (Figure 2a,c). Of the remaining nine Geographic Areas of the US (as delineated by the National Interagency Fire Center), only three reported an increase in prescribed fire over the period of record (Figure 2b,d), while the remainder reported a decrease. Excepting a strong increase in prescribed fire in the Eastern GACC and a strong decrease in the Great Basin, however, the slopes for all other units were so small that they were essentially rendered flat, even when the GACCs were normalized by area. This is particularly reflected in rank correlation coefficients, where only the Southern, Eastern, and Great Basin GACCs demonstrated a strong trend (i.e., a Spearman's Rho value greater than 0.5) (Table 1).

Table 1. Trends in prescribed fire accomplishments in the United States (US) by Geographic Area Coordination Center region (GACC) from 1998 to 2018, including raw trend (mean ha/year), relative trend (normalized by mean accomplishment for a given GACC), percent of the total US accomplishment, percent of the total US trend, and Spearman's Rho to indicate the strength of the trend.

GACC	Trend (ha/yr)	Rel. Trend (%)	% of US Total	% of US Trend	Spearman's Rho ¹
Alaska	253	3.1	0.7	0.4	0.29
Northwest	-861	-1.9	4.2	-1.4	-0.47
N. California	-404	-2.0	1.8	-0.7	-0.48
S. California	-160	-2.3	0.6	-0.3	-0.29
No. Rockies	-501	-1.7	2.8	-0.8	-0.45
Great Basin	-1228	-4.5	2.5	-2.0	-0.64
Southwest	-170	-0.3	6.1	-0.3	-0.07
Rocky Mtns	246	0.7	3.4	0.4	0.10
Eastern	4023	4.8	7.6	6.5	0.74
Southern	60,480	7.9	70.1	98.1	0.67
TOTAL	61,678	5.7	100.0	100.0	0.61

¹ Correlation coefficients below -0.5 or above 0.5 are considered strong trends and are more meaningful than *p*-values in such a small dataset.

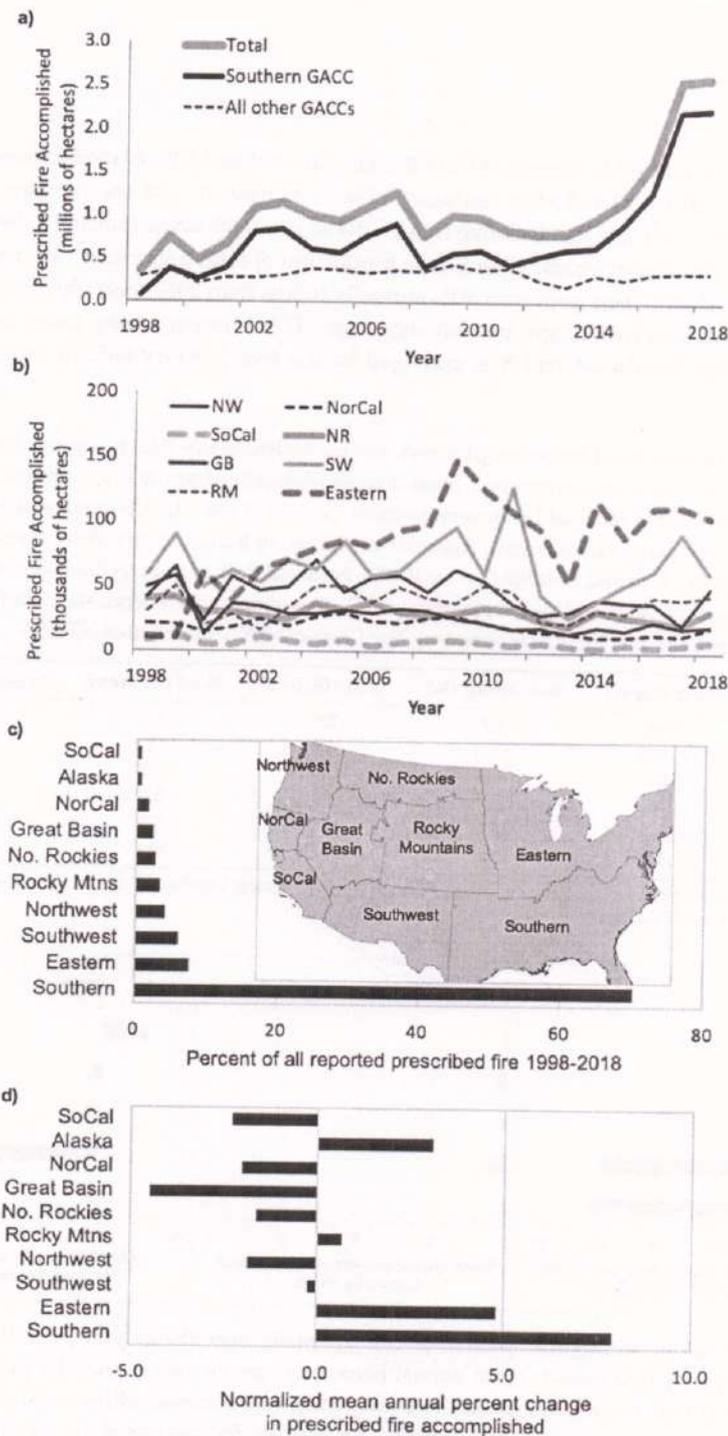


Figure 2. Prescribed fire accomplished in the United States (US) from 1998 to 2018 across Geographic Area Coordination Center (GACC) regions, including (a) total area burned (in millions of hectares), area burned in the Southern Geographic Area (GACC), and area burned in all nine other GACCs; (b) area burned (in thousands of hectares) in the eight other contiguous US GACCs (excludes Alaska and Southern); (c) proportion of all reported prescribed fire over the 21-year period by GACC; and (d) the normalized (by mean annual total accomplishment per GACC) mean annual change in prescribed fire completed, ranked by (c).

Similarly, when stratified by agency, 39% of the 21-year total and 93% of the increase in prescribed fire was accomplished by State/Other entities (Table 2, Figure 3). Of the primary federal land management agencies, only the BIA (relative trend = 3.7%; $r_s = 0.68$) accomplished substantially more prescribed fire over the study period. Overall, the proportion of total prescribed fire completed by US federal agencies has diminished from over 90% annually to less than 30% annually across the past two decades as the State/Other totals have steadily increased. This is unsurprising given regional trends, as less than 7% of the Southeastern US is managed by the five primary federal land management agencies (Table S1).

Table 2. Trends in prescribed fire accomplishments in the United States (US) by agency from 1998 to 2018, including raw trend (mean ha/year), relative trend (normalized by mean accomplishment for a given agency), percent of the total US accomplishment, percent of the total US trend, and Spearman's Rho to indicate the strength of the trend. Agencies are Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), Fish and Wildlife Service (FWS), National Park Service (NPS), US Forest Service (USFS), and other federal (e.g., Defense, Energy, and Reclamation), non-federal, state, and municipal agencies that report to the National Interagency Fire Center (NIFC) (State/Other, ST/OT).

Agency	Trend (ha/yr)	Rel. Trend (%)	% of US Total	% of US Trend	Spearman's Rho ¹
BIA	1164	3.7	2.9	1.9	0.69
BLM	-1335	-3.0	4.1	-2.2	-0.47
FWS	518	0.6	8.6	0.8	0.05
NPS	397	1.0	3.6	0.6	0.09
USFS	3353	0.7	41.3	5.4	0.74
ST/OT	57,582	13.4	39.5	93.4	0.74

¹ Correlation coefficients below -0.5 or above 0.5 are considered strong trends and are more meaningful than *p*-values in such a small dataset.

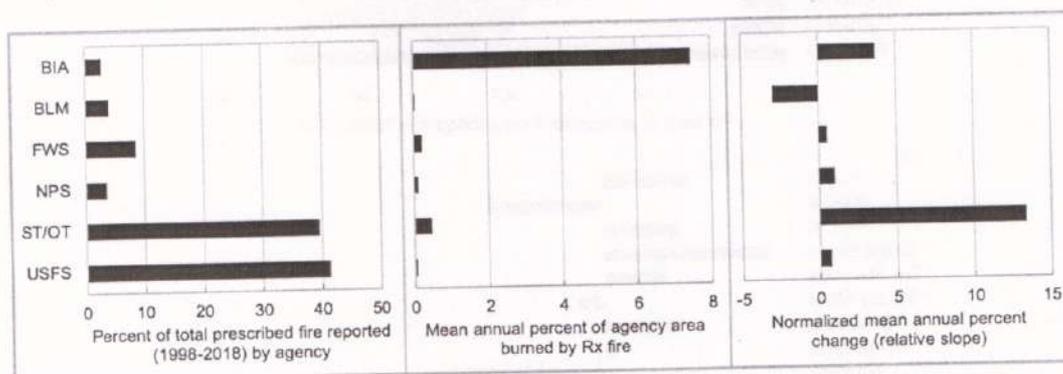


Figure 3. Percent of all reported prescribed fire nationally over the 21-year period (1998–2018) stratified by agency (left panel), mean annual percent of agency area burned by prescribed fire (i.e., area-normalized mean accomplished; center panel), and normalized (by mean annual total accomplishment per agency) mean annual change in prescribed fire completed (i.e., relative slope per agency; right panel).

4. Discussion

The Southeastern US accomplished over twice the amount of prescribed fire as the entire rest of the US combined between 1998 and 2018. This may be one of many reasons why the Southeastern states have experienced far fewer wildfire disasters relative to the Western US in recent years [17,33]. The amount of prescribed fire reported in the Southeastern US is also likely underreported, as the Southeastern states have purportedly accomplished millions of hectares of prescribed fire annually for decades [34–37]. However, until 1998 there was no central prescribed fire reporting in the US. Even after 1998, non-federal entities did not necessarily report the full scope of their accomplishments in the federal reporting system.

The dramatic difference in prescribed fire completed between east and west reflects both a broad socio-cultural divide over fire [29] and a problematic dichotomy between federal and non-federal fire management. Biophysical conditions have often been highlighted as a challenge to prescribed burning in the Western US; the topography is more complex and inaccessible, burn windows are narrow, and fuels have built up throughout decades of fire exclusion [23,38]. By contrast, the Southeastern states have both the most extensive Wildland–Urban Interface in the US [39] and some of the worst air quality challenges associated with prescribed fire due to higher humidity (e.g., increased smog formation). That agencies are able to accomplish so much prescribed fire in such a populated region likely also reflects social acceptance in addition to more conducive conditions. It is also telling that no single Southern state is driving the regional trend. State summaries in the Historical Wildland Fire Summary reports indicate that Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Texas all completed an average of over 40,000 ha per year each from 2002 to 2017.

Prescribed fire is widely accepted as a tool in the Southeastern states, where residents are more accustomed to using controlled fire to enhance timber production, control the rapidly growing vegetation, and enhance game species habitat [29,34]. Some states, such as Florida, even have laws that recognize prescribed fire as being in the public interest and protect landowner rights to utilize it [40]. Although studies throughout the US have shown that residents in all regions broadly support the concept of prescribed fire, they fear the potential for escaped fires and they are also highly concerned about smoke impacts [41]. However, Engebretson et al. [42] found significantly higher tolerance of prescribed fire smoke from Southern-state residents than those in Western states, which suggests that this tolerance may translate into less opposition to using prescribed fire in the Southern GACC. This is true for either federal or non-federal agencies in the region; the Historical Summaries indicate that much of the USFS annual prescribed fire accomplishment occurs in the Southern GACC states (particularly along the Gulf Coast) rather than in the Western states where the greatest proportion of USFS land lies.

By contrast, fire managers in the Western US face considerable social barriers to using prescribed fire, including negative public perceptions of risk of escapes and smoke [29,42]. This high perception of risk has been cemented by the occasional escaped prescribed fire, but it has likely also become entrenched due to the absence of prescribed fire demonstrated here. Fire managers, particularly federal fire managers, receive insufficient incentive to use prescribed fire under current agency policies that incentivize fire suppression (e.g., with overtime pay and promotion) but penalize risk-taking, particularly when escaped prescribed fires occur [29,43]. Additionally, federal funding for prescribed fire and other fuel reduction activities has been drastically depleted over the past two decades as large wildfires force federal agencies to expend allocated funds on suppression rather than prevention [35–37].

Of the federal agencies reporting individually (i.e., separate from the ST/OT class), only the BIA has been able to substantially increase the relative use of prescribed fire. This increase is particularly striking because a higher proportion of tribal lands managed by BIA have been subject to prescribed fire than for any other agency, with a mean of 7.5% of tribal lands burned each year (Figure 3). This may reflect the more recent efforts of tribes seeking to reclaim sovereignty on their ancestral lands through increased self-governance and drawing upon TEK to re-introduce extensive intentional fire in these landscapes [25], particularly following the 2004 Tribal Forest Protection Act [26]. The push for more prescribed fire among tribes is also reflected in the BIA budget for prescribed fire, particularly compared with the fire suppression budget. BIA devotes the second-highest budget of the five primary land management agencies to prescribed fire (behind USFS), but the prescribed fire budget is between 50% and 80% of its fire suppression budget, while no other agency's prescribed fire budget has exceeded 25% of its fire suppression budget in the last five years [44]. It is also worth noting that the more detailed Historical Wildland Fire Summary reports suggest that the strong positive trend in the Eastern GACC region is potentially partially a function of increased tribal burning in that region.

Despite changes in federal fire management policy meant to increase prescribed fire use, only one region of the US has considerably increased the amount of prescribed fire completed, and credit

for much of this increase goes to non-federal agencies. Given the evidence that federal agencies have not accomplished more prescribed fire across the US over the past two decades, this suggests that while the Cohesive Strategy incorporates the best available science in a top-level holistic management framework, federal agencies have not made sufficient policy changes or budgetary allocations to carry out the Strategy.

There is considerable evidence in the scientific literature that prescribed fire is the most effective means of reducing the risk of wildfire disasters and increasing ecosystem resilience across much of the US. However, only one primary federal land management agency has substantially increased prescribed fire use, and the only widespread use and acceptance of prescribed fire is in the Southeastern states. Federal and non-federal entities have used the prescribed fire expertise of the Southeastern region as a training ground for fire and fuel managers across the US, but this has not translated to increased prescribed fire use. This suggests that a larger cultural shift in public sociocultural perceptions of prescribed fire is needed to truly capitalize upon the utility of prescribed fire and more aggressively reduce wildfire risk. Without such a shift, more catastrophic wildfire disasters are inevitable.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2571-6255/2/2/30/s1>, Table S1: Hectares under each primary land management agency by Geographic Area Coordination Center (GACC) region.

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Prescribed fire management

Marcos Francos¹ and Xavier Úbeda²

Abstract

Fire plays a role in the vast majority of terrestrial ecosystems. Researchers have discovered that the negative effects of prescribed fire on soil, water and vegetation are transitory, and that benefits are much greater. This paper presents a synthesis of the most important recent work on the effects of prescribed fire on soil, water and vegetation and assesses the validity of the use of fire as a management tool. The impact of fire is low and temporary, whereas the benefits are greater both directly (e.g. reduction in vegetative fuel and the risk of fire, noncontamination of water) and indirectly (e.g. improvement in forest health). Thus, prescribed burning is a good management tool and should be incorporated into land management and regional planning. Researchers, managers, stakeholders and landowners must be taken into account to increase knowledge of this management tool and implement it in the most optimal way possible.

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Soil degradation, Forest management, Fire ecology, Water quality, Vegetation recovery, Fuel load.

Introduction

Fires are a key ecological factor in the earth system [1]. However, as many cultures have used fire for management purposes considering people safety and hazard-ousness, even though it was previously known to have a low impact on soil, water and vegetation. Soil is one of the most valuable non-renewable resources [2]. In forest areas, soil can be degraded by high-severity fires [3], but

low-severity fires, as is commonly the case of prescribed fires, minimise the adverse effects of fire on soil and are often beneficial [4]. They have thus proved to be a good forest management tool, and even more so in areas of high fire recurrence [5**]. Depending on its intensity, fire can affect water quality, furthermore following wildfires. However, marked changes in water quality have not been found after prescribed fire compared with prefire water quality [6]. A prescribed fire will immediately eliminate grasses and some shrubs but the fire will quickly be followed by an increase in herbaceous species and a decrease in the percentage of terrain occupied by woody species [7]. The vegetation response after a prescribed fire mainly depends on fire intensity and frequency, the two factors that influence cover dynamics over time [8]. Prescribed fire is often used for environmental and land management, and controlled burning has proved a good tool to manage large forest areas in cases where economic resources are limited, being economically beneficial and feasible for land management [9]. This type of management can be an extremely effective mean to prevent shrub invasions [10*] and facilitate the colonisation or recovery of keystone species of flora [11] and fauna [12,13]. Given the body of scientific, theoretical and practical evidence, fire exclusion has been reconsidered and abandoned in almost all ecosystems across the world to instead incorporate this type of management in regional and territorial planning [14,15]. Furthermore, some decades ago, fire used to be employed for forest management, but developments in modern forestry erroneously excluded fire from the reproduction of natural processes and focused instead on fire suppression [16]. The use of prescribed fire reduces wildfire risk and creates habitats for grazing and wildlife [17]. It is therefore essential to educate stakeholder groups who influence prescribed fire policies to change policy regulations that in many cases present legal barriers to implementing effective ecosystem management strategies such as prescribed fire [18]. A prescribed fire is a use of low-intensity fire under planning to achieve different goals in different weather, fuel and topographic conditions therefore, it is essential to analyse how they influence the environment to take them into account in territorial management [5**,17].

This review is organised as follows. First, we examine the impact of prescribed fire on soil, vegetation and water and the implications for its use as a management

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tool. Then, we summarise the benefits and drawbacks of this tool, which is used worldwide for environmental and territorial management. To perform this review, we conducted a literature search for scientific articles published mainly in English over the last two decades in the Scopus Database. In some cases, earlier studies were consulted for the explanation and discussion of certain dynamics. The search terms used were: "prescribed fire" or "prescribed burning" or "controlled fire" and "soil properties" or "vegetation" or "plant" or "water" or "management tool" or "planning", and this search was combined with another in Google Scholar.

The effects of prescribed fire on soil, water and vegetation

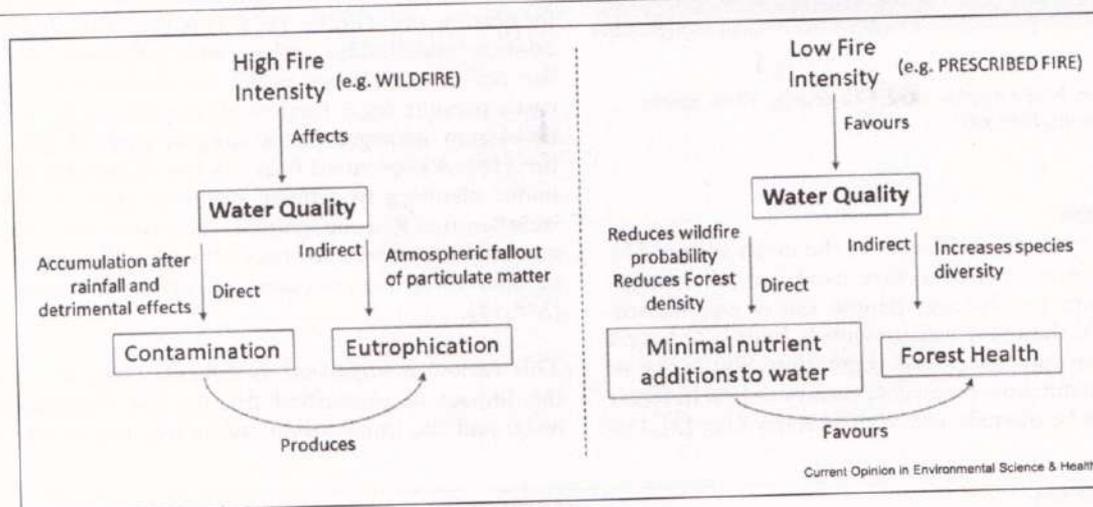
Prescribed fire can have long-term benefits such as increased soil sorption capability [19], optimisation of soil quality to improve forage for livestock [20] and enhanced proliferation of microbial communities [21*]. In other cases, although the post-fire levels of some chemical elements do not reach prefire values, especially in the short-term [22], prescribed fire can still achieve the proposed management objectives [23]. Prescribed fire exerts positive, neutral or negative effects on soil depending on the soil properties studied, but its impact is always lower than in the case of a wildfire, indicating that this tool is a good alternative in fire-prone areas and extensive highland areas, offering reduced costs compared with other forest management practices [5**].

Groundwater chemistry is not directly affected by prescribed fire because such fires do not burn with sufficient intensity to change the chemical elements in

water [24,25]. Indeed, fire intensity is the most important factor to consider when studying the impact of prescribed fire on water quality (Figure 1). Only in some cases have slight increments on water nutrient loading been detected after a prescribed fire [26,27], but such post-fire increments are unlikely to impact watershed resources [28*,29*] sometimes being beneficial for water quality and human health decreasing the amount of contaminants as benzene and ethylbenzene both known carcinogen [30,31]. As regards water content, prescribed fire may increase soil water content immediately after fire but can be detrimental to the germination process in the second and third growing seasons [32]. Prescribed fire not only increases the amount of water available but also increases the efficiency with which some species use that water, which is of great importance in water-limited ecosystems [33].

Fire reduces the vegetative fuel load, and this effect persists for about 15 years in Mediterranean ecosystem. There are regions where this period of time is much shorter because climate conditions promote fast vegetation growth and rapid fuel load recovery/increment and therefore reaching the long-term needs more or less years depending on one ecosystem or another. After that, the area will be dominated by shrubs, decreasing herbaceous, and plant diversity and requiring a new prescribed fire [43]. As regards short-term effects, in the first year after a prescribed fire, there is a reduction in shrub cover, an increase in herbaceous cover and a reduction in plant diversity. Despite these changes, the overall amount of forage two years after a prescribed fire remains unchanged compared to unburned areas, but the quality of forage for grazing cattle increases [44]. In the medium- to long-term, prescribed fire does not change vegetation

Figure 1



Influence of fire intensity on water quality. This figure is based on references [6,24–26,28*,29*,34–42].

communities, confirming its beneficial effects and indicating that it could be repeated after a few years [45]. In many cases, prescribed fire promotes pine and oak regeneration [46], enhances understory vegetation communities, increases species richness, diversity and cover in oak woodlands [47] and can establish a successional trajectory towards a sagebrush steppe vegetation structure as against pinyon and juniper species on single-leaf pinyon — Utah juniper woodland (*P. monophylla* Torr. & Frém. — *J. osteosperma* [Torr.] Little) (Marking Corral) and a Utah juniper woodland (Onaqui) [48*].

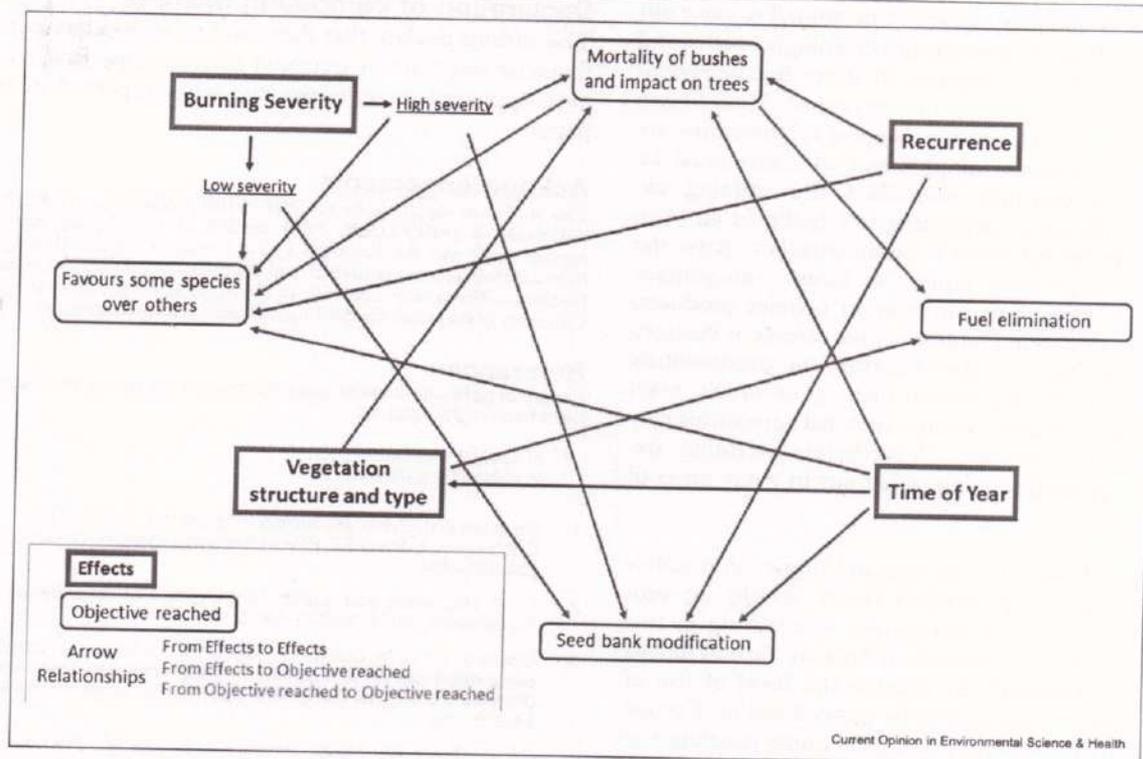
The effects of burning on vegetation can be direct or indirect and can occur from the level of seed banks to the herbaceous, shrub and arboreal strata. The mortality in each stratum is given by the burning objectives, which are summarised in the figure given in the following context, together with the four most important variables to consider: burning intensity, type and structure of vegetation, time of the year when burning takes place and recurrence of burning (Figure 2).

Prescribed fire as a management tool

Prescribed burning is not yet fully accepted worldwide as a management tool. Many countries see fire as a risk rather than a resource. In fact, until technical and scientific evidence supported the use of fire as a

management tool for forests and other land uses, nearly all governments held this view. In Australia, however, prescribed burning has been carried out on a recurring basis since the 1960s for the purposes of wildfire mitigation, agricultural practices such as stubble reduction and grazing land management, property protection, the maintenance of ecological processes and biodiversity conservation [53**]. These same authors describe the areas in Australia where prescribed burning is implemented, which coincide with those where the most intense fires have occurred due to the type of vegetation and climate [54]. Although the authorities' use of prescribed fire has increased since the 1960s, growing environmental awareness since the mid-1980s has prompted questions about whether prescribed burning has negative environmental effects, triggering a reduction in its use [53**]. Aware of social concern about the possible environmental effects of prescribed fires, researchers and scientists began to publish many more articles and technical reports, with publications rising from 70 in the 1970s to 205 in the 1980s [55]. These authors also highlight an increase in the 1990s in articles focussing exclusively on the ecological effects. Interestingly, in an exhaustive review of studies published in Australia, Oliveras and Bell [54] did not find a single publication that completely ruled out the use of fire as a management tool.

Figure 2



Prescribed burning and vegetation: objectives, effects and relationships. This figure is based on references [4,49–52].

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A recurrent question in many countries regarding the use or not of prescribed fire for management is whether fire is a natural phenomenon, or more accurately, if a significant proportion of forest fires are started by natural causes. In southeast Australia, large fires have been recurrent throughout history, and many of them have had a natural cause such as lightning strikes in dry storms, according to Styger et al. [56], whereas in Tasmania they have increased since the 2000s as a consequence of longer, more intense dry spells. Perceiving the causes as natural renders the use of fire for land management more acceptable. Recent technological advances such as the use of satellite images to verify burning intensities, the application of different fire use models depending on the type of vegetation [57] to be managed and the use of fire propagation simulators [58] have all increased perceptions of the use of prescribed fire as acceptable and even necessary [53**] because of climate change and evidence that the climate in southeast Australia is becoming warmer and drier [59].

According to Spencer et al. [60], the use of prescribed fire is fully accepted in the United States, but there are barriers to its increased use, perhaps the most important being a lack of qualified, available personnel to carry out prescribed burning at ecologically meaningful scales and in sufficiently large landscapes to affect fire behaviour and restore key components of ecosystems. According to Walker and Salt [61], socio-ecological relationships are becoming increasingly complex and all actors must be involved to strengthen prescribed fire training exchanges. Furthermore, according to Chaffin et al. [62], this can only be achieved if administrations have the capacity to adapt more rapidly to forest management needs in the USA. Fire suppression policies produced catastrophic effects in Ponderosa pine forests of Western US [63]. In Europe, the situation of professionals trained to carry out prescribed fires varies widely, even within the same States, because regional authorities may apply different policies. Nevertheless, training exchanges are gradually being rolled out in many areas of Europe.

There is also debate, for example in Europe, on whether those carrying out prescribed burns should be professionals who work for companies specialising in this practice. In Spain, all prescribed fires are carried out by government personnel. As regards the level of use of prescribed burns, this cannot be generalised for Europe as a whole or even within States because restricted or even prohibited land management practices vary depending on local authorities [64]. In some European countries, laws are often based on 19th century ordinances on the use of fire, although these may now seem obsolete. Nevertheless, prescribed fire is used for forest management in many European countries, including Sweden, the United Kingdom and Germany in the

northern Europe, France and Spain in southern Europe. In none of these cases is this practice governed by a single regulation, and in some cases it is restricted to highly specific territories [65].

Final remarks and conclusions

Prescribed fire is a good tool for forest management, especially in fire-dependent ecosystems. The harmful effects of these low-intensity fires on soil, water and vegetation are few and transitory, whereas the benefits are long-term and much greater than the damage. Therefore, the use of prescribed fire should be implemented formally through regional planning and should seek stakeholders' engagement, knowledge and experience to ensure community inclusion [66]. Involving the community is essential to the success of this type of management, as is changing perceptions of controlled fire to see it as it is: a good environmental and territorial management tool. It is therefore also necessary to educate the public about controlled fire and promote its use in order to gain public support. In sum, prescribed fire represents an unparalleled forest management tool that provides maximum ecological benefit with minimum effort.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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- * of special interest
- ** of outstanding interest

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Managing forest fuels using prescribed fire – A perspective from southern Australia

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ABSTRACT

Prescribed fire has been used in a coordinated manner to manage fuels in eucalypt forests of southern Australia since the 1950s. The impetus for planned use of fire arose from the need to reduce the impact of extensive, high intensity fires on life, property and commercial forest values. Prescribed fire is increasingly recognised as also playing an important role in mitigating undesirable effects of high intensity fires on environmental values including soil, water and biodiversity. Critical elements for an effective prescribed fire program include a sound understanding of fire behaviour, an experienced and flexible workforce, and organisational commitment to adaptive management involving planning, monitoring and applied research. Implementation of prescribed fire programs has been closely linked with, and dependent upon, the development of burning guides for particular forest types through empirical field research. The contribution of prescribed fire to mitigating the effects of extensive, high intensity fires can be quantified in a variety of ways using basic combustion science, well-documented case studies, analysis of fire statistics, and simulation. Fuel reduction can improve the safety, efficiency and effectiveness of fire suppression, although these effects may be subtle and difficult to measure. Social and political factors can significantly influence the conduct and effectiveness of prescribed fire programs, and effective engagement with the community during planning, implementation and post-fire monitoring phases is essential to ensure that the role of prescribed fire in land management is properly recognised and understood.

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1. Introduction

Prescribed fire has been used in a coordinated manner to manage fuels in eucalypt forests of southern Australia since the 1950s. The impetus for planned use of fire arose from the need to reduce the impact of extensive, high intensity fires on life, property and commercial forest values. These fires followed in the wake of disruption of traditional aboriginal burning patterns, broadscale clearing of land for agricultural development, and commercial exploitation of forests that generated large amounts of logging debris and introduced new sources of ignition from settlements, steam locomotives and machinery. Major bushfires such as Black Sunday (February 1926) and Black Friday (January 1939) in Victoria, and the 1961 bushfires that destroyed the towns of Dwellin-gup, Nanga Brook and Karridale in south-west Western Australia have come to be regarded as defining moments in Australian history (Pyne, 1991). The Australian experience is not unique and a similar pattern of events can be traced in the fire histories of the United States, Canada and other countries undergoing rapid settlement and economic development of the land during the 19th and first half of the 20th centuries (Pyne, 1995). Cessation of land clearing and the transfer of extensive tracts of public land into reserves

managed primarily for recreation and nature conservation has not, however, been accompanied by a reduction in the extent and impact of destructive fires. During the first decade of the current century unplanned fires burnt more than 3 million ha of public land in south-eastern Australia culminating in the destructive fires of Black Saturday 7 February, 2009 when 173 lives were lost and more than 2000 buildings destroyed in the state of Victoria (Ellis et al., 2004; Teague et al., 2010). The size and impact of unplanned fires also increased in south-west Western Australia during this period, although the scale of losses has been considerably less than in south-eastern Australia.

The economic, social and environmental impacts of unplanned fire at a global scale have increased substantially during the past decade (Williams et al., 2011). Fires having unprecedented consequences in terms of loss of human life, suppression cost, economic loss and natural resources impacts have occurred in Australia, Mediterranean Europe, Russia, the United States and parts of south-east Asia and South America. Many factors contribute to the increasing impact of fire including population growth in peri-urban communities (Stephens et al., 2009; Syphard et al., 2009), altered patterns of land use in rural areas (Pausas et al., 2008), persistent drought at regional scales (Cook et al., 2004; van Ommen and Morgan, 2010; Gergis et al., 2012), and changes in forest structure and fuel dynamics linked to climatic stress (Allen et al., 2010) and land management practices (Stephens

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and Ruth, 2005). The term 'mega-fires' has emerged to characterise fires that simultaneously exhibit extreme values of economic and social impact, environmental consequence and resistance to suppression (Williams et al., 2011; Williams, 2013). Reaching broad international agreement on a formal definition of mega-fire may prove difficult because of differing perspectives amongst policy makers, managers, practitioners and scientists working in the fire arena, and because of profound differences between societies in the way that fire is managed. Nevertheless, rigorous evaluation of the concept of mega-fires is useful because it may help to identify common trends in the scale and impact of fire emerging across biomes and jurisdictional boundaries.

Eminent fire historian Stephen J. Pyne observed that Australia, far more than any other industrialised nation, has held to a tradition of prescribed burning, attributing this to the fact that no single institution has been sufficiently powerful to impose its will on the land, and that eradication of fires is unachievable in a land characterised by flammable vegetation, drought and dry winds (Pyne, 2003). In the Australian context prescribed fire refers to the application of fire under specified environmental conditions to a predetermined area and at a time, intensity and rate of spread required to attain planned resource management objectives (AFAC, 2012). Prescribed burning originated as a tool for fire protection in forests (McArthur, 1962; Peet, 1965; McCaw et al., 2003), but its use has broadened in recent decades to include regenerating areas following timber harvesting, and managing habitat for biodiversity conservation (Burrows, 2008). Prescribed burning also plays an important role in mitigating undesirable effects of unplanned high intensity fires on soil and water values (Certini, 2005). These aims need not be mutually exclusive and in practice all burning achieves some level of fuel reduction. Fires used to reduce fuels in eucalypt forests are typically of low to moderate intensity with fireline intensities (Byram, 1959) in the range 500–2500 kW m⁻¹, and are implemented at scales ranging from tens of hectares ignited by ground crews through to thousands of hectares ignited using aerial ignition.

An Australian perspective on the use of prescribed fire for managing forest fuels should be of interest to the global fire community which is facing the challenge of escalating socio-economic and environmental impacts from unplanned fires. This paper examines (1) the scientific knowledge base underpinning the use of prescribed fire for fuel reduction in eucalypt forests, (2) approaches to evaluate the effectiveness of prescribed fire in mitigating the impacts of high intensity unplanned fires, and (3) contemporary influences on the implementation of prescribed fire programs in southern Australia, particularly in the states of Western Australia and Victoria.

2. Forest fuels and fire behaviour in southern Australia

This paper is concerned primarily with open eucalypt forests, also commonly known as dry sclerophyll forests, which at maturity can attain a height of 30 m and overstorey foliage cover of 30–70% (Specht, 1970). Open eucalypt forests are widespread in southern Australia in areas with a temperate or Mediterranean-type climate receiving mean annual rainfall >500 mm, and occur on a broad range of soils and landforms including plateaus, ranges and plains (Boland et al., 2006; Gill, 2012). Prescribed burning is also undertaken in some tall open forests with eucalypts up to 80 m in height, particularly forests dominated by *Eucalyptus diversicolor* in south-west Western Australia.

The fuels in a eucalypt forest can be categorised into a series of strata according to particle size, arrangement and potential contribution to fire behaviour (Gould et al., 2011, Fig. 1). Fuel strata include those which:

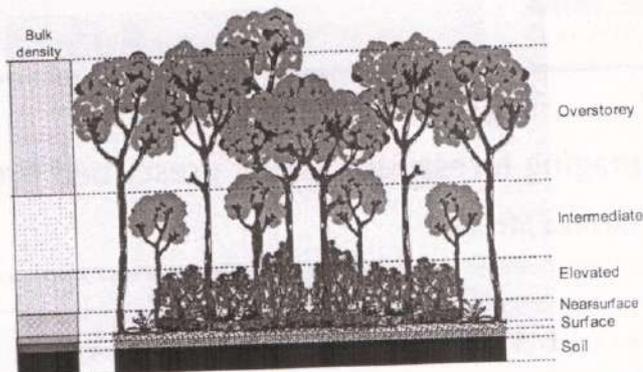


Fig. 1. Visually distinct fuel layers within an open eucalypt forest in southern Australia (Source: Gould et al., 2011). Grey scale on the left side indicates the relative bulk density of each layer.

- contribute to the flame height: primarily the loosely compacted layer of leaf litter, twigs and low shrubs on or near the forest floor;
- contribute to the depth of flame behind the fire front: mostly the upper part of the leaf litter layer and the larger twig components (6–25 mm diameter) embedded in it;
- contribute to smouldering combustion: the lower compacted part of the leaf litter layer, sometimes referred to as duff, and dead fuels >25 mm diameter, decorticated bark of stringybark types, which may contribute up to 10 t ha⁻¹ and burn for hours;
- burn only when supported by the combustion of fine dead fuels: these are generally sparse elevated dead fuels, live fuels (including canopy) and some dead fuels;
- do not burn because of their location, moisture content or size (e.g. live trunks, moist logs).

Important characteristics of fire behaviour in eucalypt forests identified by Luke and McArthur (1978) and in a recent review by Sullivan et al. (2012) include the potential for rapid rates of forward spread (up to 10 km h⁻¹), crowning and massive spotting with firebrands transported up to 30 km downwind under extreme fire danger conditions (Ellis, 2011; Cruz et al., 2012).

Until recently, fuel load (mass per unit area) was the only fuel characteristic used in Australian forest fire danger rating systems to predict fire behaviour. Studies by McArthur (1967, 1962) and Peet (1965) suggested that the amount of fine fuel (<6 mm diameter) available on the forest floor (i.e. fuel consumed by the fire) was the most significant fuel variable affecting the spread of fires in eucalypt forests. These authors claimed that, for fixed temperature, humidity, drought factor and wind speed, the rate of spread of the headfire (R) is directly proportional to the load of fine fuel (W) consumed and is expressed as a simple linear relationship:

$$R = aW \quad (1)$$

where a is a constant derived from field experiments in a specific fuel type. Fireline intensity (Byram, 1959) is usefully correlated with flame dimensions, difficulty of fire suppression, and a broad range of effects of fire on the environment (Cheney, 1990). Intensity (I) is calculated as the product of fuel load consumed in the flaming zone (W) and rate of spread (R) according to the formula:

$$I = HWR \quad (2)$$

where H is the heat yield of the fuel in units of kJ kg⁻¹. If the rate of spread is directly proportional to fuel load, it follows that reducing the fuel load by half, halves the rate of spread and reduces the intensity of the fire fourfold. This relationship between fuel load, rate of spread and fire intensity has provided a simple but powerful

argument to support fuel reduction burning in eucalypt forests for more than 50 years. However, McArthur (1967, 1962) and Peet (1965) provided no detailed description of analytical methods or confidence limits on the correlation between rate of spread and fuel load. Their relationships were generally based on data from low to moderate intensity fires ($<2500 \text{ kW m}^{-1}$) lit at a point and allowed to develop for periods of up to 1 h in fuel composed predominantly of leaf litter and low shrubs.

The relationship between age-related fuel characteristics and fire behaviour in open eucalypt forest was investigated during a comprehensive series of field experiments known as Project Vesta (Gould et al., 2007; McCaw et al., 2012). Simultaneous experimental fires were conducted under dry summer conditions at two locations with contrasting understorey and fuel structures that had developed over periods of 2–22 years after prescribed burning. Most fuel characteristics including bark, understorey shrubs, near-surface and surface fuels increased with increasing time since last fire, and visual hazard scores described patterns of fuel dynamics over time in a similar fashion to models based on fuel load accumulation (Gould et al., 2011). Fuel hazard scores that reflect the quantity and arrangement of surface and near-surface fuel were more strongly correlated with most fire behaviour variables than were corresponding fuel load variables. The near-surface fuel layer of suspended leaves, bark, twigs and low shrubs was found to be the dominant stratum affecting headfire rate of spread during these experiments. Visual ratings of fuel structure have been included in new algorithms to predict fire behaviour and fire threat in open eucalypt forests (Cheney et al., 2012). Fine fuel load remains an important consideration in fire behaviour prediction because of its contribution to fireline intensity. By providing a better understanding of how different fuel strata contribute to fire behaviour, findings from the Project Vesta experiments also provide a sound basis to assess the effectiveness of fuel reduction treatments in modifying the behaviour of high intensity fires burning under dry conditions.

3. Quantifying the effectiveness of prescribed fire

Fire behaviour is influenced by fuel quantity and arrangement, fuel dryness, wind speed, and slope. Fires burn more intensely when fuels are continuous, well aerated and dry, when winds are strong enough to deflect flames forward and pre-heat fuels in advance of the flame front, and for the same reason when a fire is advancing up a slope (Sullivan et al., 2012). In the simplest case, the reduction of fire behaviour immediately following fuel removal by prescribed burning is obvious as there is no surface fuel to burn, and even crown fires may collapse within a short distance after encountering a recently fuel reduced area. As fuel re-accumulates in subsequent years the benefits of prescribed burning for fire suppression will be evident in the form of reduced rate of spread and fire intensity, and reduced fire propagation by spotting. Thermal impact on vegetation and soils will also be lessened, commensurate with the reduced fire intensity. Eventually, at some time after burning, fire behaviour in the treated area becomes indistinguishable from that in adjoining forest that has not been subject to fuel reduction treatment. The challenge, therefore, is to quantify in some practical way:

- how the effects of fuel reduction vary with weather conditions and fuel dryness;
- how long the effects of fuel reduction persist, and;
- how fuel reduction contributes to an overall reduction in damage from unplanned fire.

Fernandes and Botelho (2003) comprehensively reviewed the effectiveness of prescribed burning for fuel hazard reduction draw-

ing on information from North America, Australia and Europe. Their paper represents an important milestone in the fire management literature and has been widely cited. They concluded that the hazard reduction benefits of prescribed fire are easily demonstrated by fire behaviour theory, through observation and measurement of post-treatment fuel changes in experimental or operational burns, and by computer simulation at the plot, stand and landscape levels. Analysis of modifications in fire regimes induced by prescribed burning was identified as the best approach currently available to evaluate the effectiveness of fuel management programs, despite the fact that separating the effects of treatment from the overall fire management effort may be difficult. Fernandes and Botelho (2003) also stressed the need for replicated studies of high intensity fire behaviour in field experiments. Each of these approaches can be informative but as with many areas of scientific inquiry, no single line of evidence is likely to be sufficiently robust or free from bias to adequately quantify the effectiveness of fuel reduction burning. Bias may be introduced by imperfect knowledge of fire behaviour, and by the opinions of the investigators themselves. An integrated approach that draws on a broad range of indicators offers the best way forward.

The extent of fuel reduction achieved by burning is critical because it determines how much fuel remains to support a subsequent bushfire. To significantly reduce potential bushfire behaviour it is necessary to:

- reduce the depth, quantity and continuity of surface and near-surface fuel which contribute directly to fire spread and flame depth;
- reduce the height of the elevated fuel layer of understorey shrubs which contribute to flame height;
- remove flammable and loose outer bark on tree stems that contributes to spotting.

The extent of fuel reduction achieved by prescribed burning depends on the amount of fuel present, the environmental conditions under which an area is burnt, and the way in which an area is ignited. Fine fuels ($<6 \text{ mm}$ diameter) in eucalypt forest respond rapidly over periods of one to several hours to changing environmental conditions including precipitation, relative humidity, air temperature and insolation (Matthews et al., 2010). Coarse fuels respond more slowly to environmental conditions over periods ranging from days to months depending on their size, initial moisture content, surface condition and state of decay (Burrows, 1987). Fuel consumption increases with more severe burning conditions and higher fireline intensities, and is maximised when both fine and coarse fuels are dry (Hollis et al., 2011a,b). More intense fires will have larger flames that consume greater quantities of live and dead foliage on understorey shrubs, and bark on standing trees (Burrows, 1997; Gould et al., 2007; Wotton et al., 2012). Fire intensity can be strongly influenced by the way that a planned burn area is ignited, in particular whether the fire is set to burn with the wind or against the wind, upslope or downslope, and whether fire is ignited as individual points or in lines (Tolhurst and Cheney, 1999). The pattern of ignition can be manipulated to increase or decrease the proportion of area burnt, particularly where there are natural barriers to fire spread in the landscape, for example rock outcrops and scree slopes, moist gullies or sand dunes. A widely spaced ignition pattern will increase the likelihood of patches remaining unburnt, even if they do support flammable fuels. Closely spaced ignition will increase the proportion of area subject to increased fire behaviour as fires originating from separate ignition points interact and coalesce.

Time elapsed since fuel reduction treatment is important because fuels re-accumulate from annual litter fall and regrowth of understorey shrubs (Gould et al., 2011). The relationship between

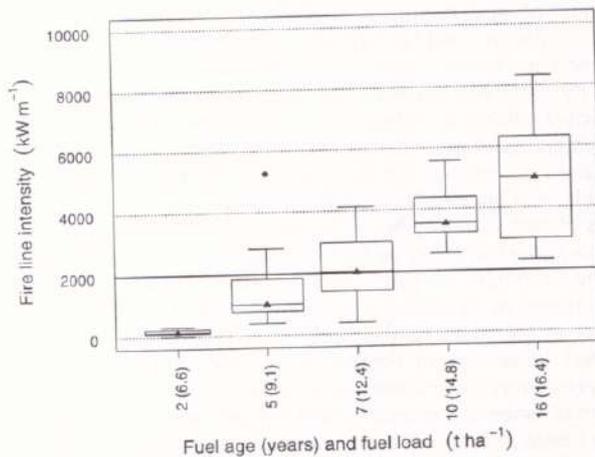


Fig. 2. Fireline intensity of experimental fires burning under dry summer conditions of moderate to high fire danger in eucalypt fuels of different age. The combined load of surface and near-surface fuel for each age class is shown in brackets. Box-and-whisker plot shows the median value (\blacktriangle), 25th and 75th quartiles (i.e. 50% of cases have values within the box) and dots (\bullet) represent outliers more than 1 box-length from the 25th and 75th percentiles. Horizontal bold line indicates an intensity 2000 kW m^{-1} above which the effectiveness of fire suppression using tankers and bulldozers declines markedly. Data for the tall shrub site from Project Vesta experiments (McCaw et al., 2012).

fuel age and fire intensity, hence suppression difficulty, is illustrated by comparing the median intensity of Project Vesta experimental fires ignited in fuels of different age under dry summer conditions of moderate to high fire danger (Fig. 2). Fires were conducted simultaneously in each fuel age so that the mean fire danger conditions for the experiments are constant. Intensities are calculated from surface and near-surface fuel loads and represent a fire that has been burning for long enough to establish a head fire at least 100 m wide. Mean fire intensity increased with increasing fuel age, and exceeded 2000 kW m^{-1} for the 10 and 16 year-old fuels. The effectiveness of fire suppression using tankers and bulldozers declines markedly once fire intensity exceeds 2000 kW m^{-1} (Loane and Gould, 1986), and these data indicate that fires in fuels older than about 7 years will be difficult to control under average summer conditions of moderate to high fire danger in open eucalypt forest. Bark continues to accumulate on the trunks of rough-barked eucalypts for many decades, adding to the difficulty of fire suppression in long unburnt forest (Gould et al., 2007).

The persistence of a measurable effect from reduced fuels has been examined in a number of studies. The effects of previous burning persisted for up to 5 years in open eucalypt forest in the Blue Mountains west of Sydney (Price and Bradstock, 2010), although this study did not explicitly account for the contribution of fire suppression in limiting fire spread. House loss resulting from the devastating Victorian fires of 7 February 2009 was significantly reduced where prescribed burning had been undertaken upwind of the property during the previous 5 years (Gibbons et al., 2012). A study of initial attack success on Victorian bushfires reported that fuel reduced areas older than about 10 years, with an overall fuel hazard of high or greater, had a low probability of assisting with suppression (McCarthy and Tolhurst, 2001). Fuel dynamics in open eucalypt forests with a shrubby understorey and fibrous-barked trees indicate that some effect of fuel reduction from prescribed burning could in fact persist for up to 15 years (McCaw et al., 2012), although this effect would be difficult to quantify and probably impossible to demonstrate with statistical certainty in the circumstances of high intensity unplanned fires.

The effectiveness of fuel reduced areas in modifying the behaviour of unplanned fires will depend on their size and location

within a landscape. In eucalypt forests prone to massive spotting, fuel reduced areas several kilometres deep are required to reduce the density of new ignitions started by spotting that suppression forces must contend with (McArthur, 1967; Ellis, 2011; McCaw et al., 2012). In southern Australia the most severe fire weather conditions are associated with winds from the north and north-west, although fires spreading on a wide front with southerly winds following the passage of a cold front have caused substantial loss of life and property (Rawson et al., 1983; Teague et al., 2009). Small fuel reduced areas will be ineffective if they are readily out-flanked by a bushfire burning through heavy fuel in adjacent areas. This was illustrated clearly during the early evening of 7 February 2009 when a southerly wind change turned the northern flank of the Kilmore East fire into a 55 km long headfire that encountered a number of areas fuel reduced with prescribed fire in the previous autumn of 2008 (McCaw, 2009; Cruz et al., 2012). Fuel reduced areas were small in size ($<2 \text{ km}^2$) relative to the scale of Kilmore East fire and had little impact on its overall spread following the wind change. Despite extreme fuel dryness, adverse fire weather conditions and the small scale of fuel reduction burns the pattern of burn severity mapped from satellite imagery clearly indicates that fire intensity was reduced within prescribed burnt areas, and for a distance of up to several kilometres downwind of them (refer to Fig. 8 in Cruz et al., 2012). A more extensive area of 3 year-old fuel north of Kinglake that resulted from a bushfire in January 2006 remained largely unaffected by the Kilmore East bushfire, despite adjacent forest being heavily crown scorched or defoliated by crown fire.

Weather conditions play a critical role in determining the extent to which fire behaviour is modified by fuel reduction, although this remains an area of considerable uncertainty. Experimental fire behaviour studies in eucalypt forest have generally been limited to conditions of high, or at most very high fire danger, for obvious reasons of safety and risk management (McCaw et al., 2012). The case study approach has been widely used in Australia to examine the behaviour of unplanned fires (Fernandes and Botelho, 2003; McCaw et al., 2008; Sneeuwjagt, 2008). Probably the earliest case study in eucalypt forest is that of McArthur (1962) who reconstructed the spread of the 1961 Dwellingup bushfires in south-west Western Australia and documented examples where fuels less than 3 years old prevented fires from crowning, even when weather conditions were extreme. Understandably, case studies of the effectiveness of prescribed burning have tended to focus on extreme weather conditions when fires pose the greatest risk to human life, property and infrastructure (Blanchi et al., 2010). The advent of remote sensing and spatial analysis techniques has assisted in quantifying the relationship between fire weather, fuel, terrain and fire severity (Keeley, 2009) at the landscape scale. Studies of this type have demonstrated that, under extreme weather conditions, the probability of crown fire in eucalypt forest is significantly reduced for up to 5 years after previous fire, in environments as diverse as the Blue Mountains of New South Wales (Bradstock et al., 2010), the Central Highlands of Victoria (Bradstock and Price, 2010), and south-west Western Australia (Fig. 3).

The contribution of fuel reduced areas to the effectiveness and safety of fire suppression under less extreme weather conditions is also important, as these are the conditions during which the majority of fire suppression work is done. Unplanned fires can grow to large size if they escape initial attack because the terrain is inaccessible to firefighters, the intensity of the fire exceeds the capacity of the resources available, or the time between detection and initial attack is protracted. All of these factors may be invoked in the circumstance of multiple lightning ignitions in remote areas, as experienced in the highlands of south-eastern Australia in January 2003 (McLeod, 2003) and December 2006 (McCarthy et al., 2012). Analysis of suppression efforts on 66 fires ignited by

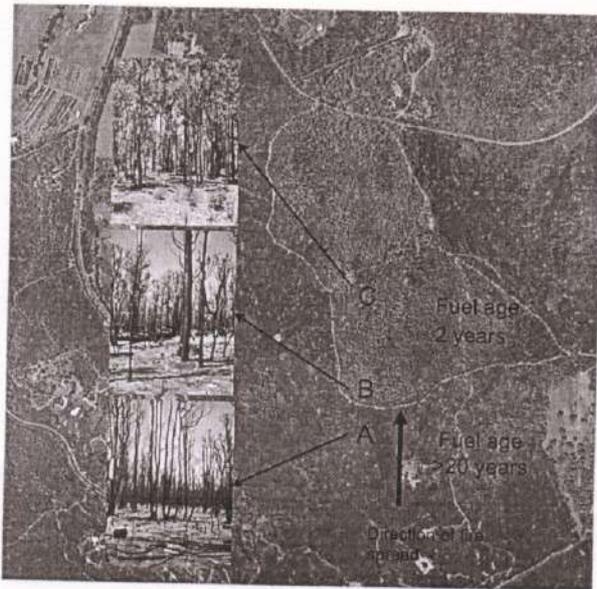


Fig. 3. Fire severity in open forest of jarrah (*Eucalyptus marginata*) near Dwellingup, Western Australia arising from a bushfire on 4 February 2007 when the McArthur (1967) Forest Fire Danger Index was 75 (Severe). Air temperature was 41 °C, relative humidity 12% and winds 35 km h⁻¹ from the north-west. Inset photographs illustrate the severity of fire at three locations identified by letters: (A) defoliation by crown fire in forest unburnt for >20 years, (B) full crown scorch of forest at the boundary between the fuel >20 years-old and forest burnt 2 years previously by prescribed fire, and (C) a patch of 2 year-old fuel within the fuel reduced forest that only burnt at very low intensity during the 2007 bushfire because the surface fuel was sparse and discontinuous.

lightning on 1 December 2006 showed that resources were allocated to fires on shallower slopes and with lower fuel hazard ratings, and that the success of containment was affected by slope, fuel hazard and weather during the subsequent week (McCarthy et al., 2012). Aerial suppression operations have been shown to be more effective where the hazard ratings of surface and near-surface fuels are lower (Plucinski et al., 2012), and backburning operations can be undertaken more rapidly and with lower risk of escape when the adjoining fuels are low. The existence of substantial areas of recently burnt forest gives fire managers the flexibility to delay initial attack in these areas while suppression resources are directed to more immediate priorities, as documented in case studies by Underwood et al. (1985) and Cheney (2010).

Analysis of the occurrence and extent of planned and unplanned fires can provide useful insight into the effectiveness of prescribed burning in managing fire regimes at the landscape scale over decadal time periods. Boer et al. (2009) demonstrated a strong inverse relationship between the extent of prescribed burning and unplanned fire in the Warren region of south-west Western Australia over 45 years, during which the fraction of the study area burnt annually by planned fire ranged from 4% to 11%. Landscape scale studies of fire occurrence in the Sydney region have shown that fuel reduction by previous fire and prescribed burning has a measurable, but limited, effect on fire spread and on the extent of unplanned fire (Price and Bradstock, 2010, 2011). The overall extent of prescribed burning in the Sydney region was small (<1% per annum). Loehle (2004) proposed the concept of leverage to quantify the extent of reduction in unplanned fire achieved for each unit of planned fire undertaken. Leverage provides a useful framework within which to analyse the effectiveness of prescribed fire for a range of management objectives including reducing the extent of unplanned fires; however, such an analysis also needs to account for the relative impacts of different levels of fire severity on natural

resource values, biodiversity and atmospheric emissions. Price and Bradstock (2011) suggested that in open eucalypt forests of southern Australia approximately three units of planned fire are required to reduce the unplanned fire area by one unit. For the Sydney region this implies an annual prescribed burning program of around 5% of the landscape would be required to halve the current extent of unplanned fire. This represents a tenfold increase on recent levels, and would bring the scale of prescribed burning up to a level similar to that undertaken in the forests of south-west Western Australia which has been effective in minimising the impacts of high intensity bushfires over a multi-decadal period (Adams and Attiwill, 2011).

4. Prescribed fire and the management of public lands

A high proportion of the forest land in southern Australia is publicly owned and managed by state agencies that have a broad charter for biodiversity conservation and other aspects of natural resource management. Agencies operate under legislation that provides them with responsibilities and powers for both biodiversity conservation and fire management. Finding an appropriate balance is not an easy task, and is made more challenging by rapid growth in peri-urban communities adjacent to public lands, changing demographics in rural communities, and the changing social and political environment in which fire management decisions are made (Bradstock et al., 2012a). Australia is a highly urbanised society and much of the population has become detached from the reality of living in a fire-prone environment, viewing fire simply as a threat to life, property and the environment.

Use of prescribed fire to achieve fuel reduction and other land management objectives has declined in southern Australia over recent decades (Sneeuwjagt, 2008; Parliament of Victoria, 2008; Boer et al., 2009; Adams and Attiwill, 2011). This decline can be attributed to a range of factors including: increased complexity of integrating fire management with land uses of public forests (e.g. timber harvesting, mining, recreation infrastructure, biodiversity conservation); changes in the timing and duration of weather patterns suitable for prescribed burning; greater awareness of and sensitivity to smoke from planned burns; and a general increase in aversion to risk arising from management activities. In Western Australia, the policy basis for the prescribed burning program on public lands has been challenged during litigation to recover commercial losses attributed to the impacts of smoke from prescribed fires on neighbouring vineyards. The court concluded that it would be unreasonable to impose a duty of care to avoid smoke damage to wine grapes on a public authority with fire management responsibilities and biodiversity conservation functions where it is not always possible to avoid some smoke during the sensitive stages of grape production (Murphy, 2010). The decision of the court was upheld following appeal (McLure et al., 2012).

Australia has a rich tradition of post-fire inquiries at State and federal level following major fire events; in the past decade these have included inquiries by independent experts (e.g. Esplin et al., 2003; Ellis et al., 2004; Keelty, 2011, 2012), parliamentary committees (House of Representatives, 2003; Parliament of Victoria, 2008; Senate Select Committee, 2010), coronial inquests (Doogan, 2006), and a Royal Commission (Teague et al., 2010). Most, if not all of these inquiries have considered the issues associated with management of fuel on public land, and have called for the use of planned fire for fuel reduction to be maintained or increased. Prescribed burning was a major focus of the Royal Commission into the 2009 Victoria fires, and generated more public submissions than any other single topic. The Commission heard evidence on prescribed burning from a range of Australian and overseas expert witnesses, and convened an expert panel to consider the

establishment of a formal target for an annual burning program on public lands; a target of 5% was subsequently set by the Victorian Government (2010). Western Australia is the only state to have consistently maintained a program of prescribed burning exceeding 5% of its public forest estate (Sneeuwjagt, 2008; Adams and Attiwill, 2011), and evidence from empirical and simulation studies in other states suggests that to significantly reduce the extent of unplanned fires requires a program of this scale (Price and Bradstock, 2011; Bradstock et al., 2012b).

Implementing an ongoing program of prescribed burning places additional demands on land management agencies beyond those traditionally associated with fire suppression response. Prescribed burning requires detailed planning and lead times of up to 5 years may be required to integrate burning with other land management activities. Effective engagement with local communities is also essential during the planning, implementation and post-fire monitoring phases. The workforce required for prescribed burning may differ somewhat to that required for fire suppression alone. Prescribed burning requires personnel to be available during the milder spring and autumn months either side of the core summer fire season, and to have the flexibility to wait for a suitable window of burning conditions to arise. Experience, continuity of service and a sound practical understanding of fire behaviour are also attributes of particular importance in prescribed burning, and are vital in maintaining corporate knowledge and practical skills.

Prescribed burning brings with it the risk of escape and unintended consequences including damage to property and infrastructure, increased area burnt under conditions that may be outside the prescribed range, and loss of confidence by government and the community in the agency responsible for undertaking the burn. These consequences were highlighted in November 2011 by the escape of a prescribed burn at Margaret River in south-west Western Australia (Keelty, 2012), and internationally in March 2012 by the escaped North Fork prescribed burn in Colorado (State of Colorado, 2012). Serious as the consequences of these escapes have been, they must in the end be balanced against the risk of not intervening to manage fuels. Risks associated with prescribed burning can be minimised by good planning and operational practice, and there is considerable scope to further minimise risk by utilising emerging capabilities for weather forecasting and modelling dynamic interactions between fires and the atmosphere (Mills and McCaw, 2010; Peace et al., in press).

5. Conclusion

Prescribed fire is a valuable tool for managing fuels in eucalypt forests in southern Australia to mitigate the behaviour of high intensity bushfires. Evidence from a variety of sources including replicated field experiments, case studies of significant bushfires, and analyses of fire occurrence at the landscape scale demonstrates that prescribed burning can reduce fire behaviour and difficulty of suppression, and reduce the likelihood of crown fire for a period of at least 5 years following burning. Studies of the effectiveness of fuel reduction in mitigating fire behaviour and the impacts of bushfire on the community have tended to focus on relatively brief periods of extreme fire weather conditions (<10 h), which is understandable given the strong association between extreme conditions and loss of life and property. However, fuel reduced areas also contribute significantly to early containment of multiple fires, provide safe anchor points for fire containment, and increase the effectiveness of suppression operations. Prescribed burning reduces the severity of bushfire impacts on soil, vegetation and other environmental values, and is an important tool for achieving biodiversity conservation and environmental management objectives in eucalypt forests.

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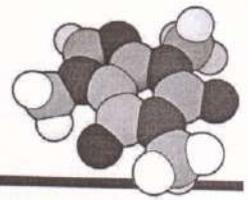
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PERSPECTIVES

ENVIRONMENTAL SCIENCE

Reform forest fire management

Agency incentives undermine policy effectiveness

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Globally, wildfire size, severity, and frequency have been increasing, as have related fatalities and taxpayer-funded firefighting costs (1). In most accessible forests, wildfire response prioritizes suppression because fires are easier and cheaper to contain when small (2). In the United States, for example, 98% of wildfires are suppressed before reaching 120 ha in size (3). But the 2% of wildfires that escape containment often burn under extreme weather conditions in fuel-loaded forests and account for 97% of fire-fighting costs and total area burned (3). Changing climate and decades of fuel accumulation make efforts to suppress every fire dangerous, expensive, and ill advised (4). These trends are attracting congressional scrutiny for a new approach to wildfire management (5). The recent release of the National Co-hesive Wildland Fire Management Strategy

(NCWFMS) (6) and the U.S. Forest Service's (USFS's) current effort to revise national forest (NF) plans provide openings to incentivize change. Although we largely focus on the USFS, which incurs 70% of national firefighting costs (7), similar wildfire policies and needed management reforms are relevant throughout the United States and fire-prone areas worldwide.

Accumulated fuels in dry forests need to be reduced so that when fire occurs, rather than "crowning out" and killing most trees, it is more likely to burn along the surface at low-moderate intensity, consuming many small trees and restoring forest resilience to future drought and fire. Mechanical thinning can reduce tree density and some fuels but is often limited by legal (wilderness and park areas), operational (steep or remote ground), and cost constraints (8). Fire can also be used to reduce fuels either intentionally (prescribed burning) or opportunistically (letting a natural ignition burn as "managed wildfire") under moderate weather conditions. Although these burns are much less precise than

Many severe wildfires are due to past fire suppression. Firefighters during the Rim Fire near Yosemite National Park, California, 25 August 2013.

mechanical thinning, in remote locations, fire is usually more efficient, cost-effective, and ecologically beneficial than mechanical treatments (9).

ENTRENCHED DISINCENTIVES. Management reform in the United States has failed, not because of policy, but owing to lack of coordinated pressure sufficient to overcome entrenched agency disincentives to working with fire. Responding to established research, official agency policy now supports a more flexible response to fire than ever before (6). Actual wildfire response, however, has changed little because of substantial management impediments. Suppression generally begets larger, more intense wildfires, which in turn intensifies agencies' suppression response (10). The alternative, working with fire, is rarely used because of liability and casualty risks and little tolerance for management errors.

For example, during the most recent decade when data were collected (ending in 2008), only 0.4% of ignitions were allowed to burn as managed wildfires (7). For individual NFs, there is little economic incentive to change because fire suppression is steadfastly financed through dedicated congressional appropriations, which are augmented with emergency funding, whereas fuels reduction and prescribed burning costs come out of a limited budget allotted to each NF and is often borrowed to cover wildfire suppression costs. With these deterrents, "battling" fire and "only you can prevent wildfire" campaigns have more traction than recognizing that many severe fires result from accrued management decisions. This skewing of agency motivation also distorts economic, insurance, and local regulatory incentives that influence development in fire-prone regions (11).

Although agencies are slow to reform internally, they may more rapidly respond to local stakeholder pressure. The core problem has been the lack of a public constituency that advocates for reform of fire-use practices (11). The benefits of greater fire use have been a difficult sell because of public objections to smoke and a negative perception of forest fires. This has begun to change as communities increasingly threatened by large fires are urging land-management agencies to accelerate fuel reduction efforts, including the use of managed fire (e.g., yosemitestanislussolutions.com and 4FRI.org). Timber companies would also benefit from more fire-resilient landscapes in which their private lands are embedded. There is growing awareness that large, severe fires are inevitable in many dry forests, especially in a warming climate. Smoke, safety threats, fire intensity, and human health risks can be better managed for public benefit with proactive fire use under favorable weather and wind dispersal conditions (12).

EFFECTING CHANGE. Public support for expanded fire use could thus be directed toward revision of each NF plan, which provides standards and guidelines for daily management decisions. Plans can divide the landscape into zones for different fire management strategies, an approach used by Parks Canada. U.S. forest plans could zone areas close to homes (wildland-urban interface) as an area where most fuels re-

duction relies on mechanical thinning and fires are suppressed. Beyond this could be an intermediate area where prescribed fire and mechanical treatment are used to optimize fuels reduction. More remote forests could be intentionally burned with prescribed fire, or lightning ignitions allowed to burn as managed wildfires under moderate weather conditions.

Three of the first eight NFs to develop new plans have proposed that more than half of their area in the southern Sierra Nevada be zoned for prescribed and managed fire use. Over the next decade, most of the 155 NFs will begin writing new plans and holding public forums. Engaged local stakeholders will need to look beyond short-term impacts of fire use (e.g., smoke, limited access, and risk of escape) to support managers working with fire and challenge suppression in remote forest zones.

Public support of NCWFMS may help overcome reform disincentives by stressing national interagency collaboration. In response to decades of problem wildfires, the U.S. Congress passed the FLAME Act in 2009 requesting development of NCWFMS, a coordinated strategy to support landscape restoration and fire-adapted communities. Coordination is essential as large, intense wildfires often cross ownership boundaries. For example, in California's 2013 Rim Fire, large patches of old-growth trees in Yosemite National Park were killed when fuel-loaded forests on nearby NF land generated extreme fire behavior that crossed into the park (13). NCWFMS can exert peer pressure between agencies and provide support for tough decisions. To accomplish these changes, some policy and resource-deployment decisions supporting fire use could be made at the national level. In the United States, federal land agencies each fund their own fire crews but the National Interagency Fire Center (NIFC) coordinates resource deployment between agencies and nationally across geographic areas. Dedicated crews could be hired and trained for managed fire use, and NIFC could be charged with deploying them for beneficial burning (14). Some local and regional agencies have briefly created such crews, but they were often pulled into fire suppression when wildfire activity increased. By giving NIFC deployment authority, it could ensure that these crews are only used for working with fire and are available to burn when weather conditions are favorable. Optimal weather and smoke dispersal conditions occur even in heavily populated and regulated areas such as California, but many burn windows are missed because crews are at or being held for wildfire deployment (9). Air-quality regulations limit prescribed fires, although they have

much lower emissions than the inevitable wildfire. The Environmental Protection Agency could consider treating prescribed fire smoke like wildfire, as an unregulated "exceptional event."

National government also has an incentive to reduce wildfire expenses and forest agencies' emergency fire borrowing. In many years, suppression costs consume 50% of agency annual budgets, which, after operating expenses, leaves little money for proactive fuels treatment or forest restoration (11). Costs and injuries, however, are much lower on managed fires than on escaped wildfires (7, 15). The estimated cost savings for using managed fire compared with wildfire suppression over the same area (15) could be reported to Congress to highlight the economy of using proactive restoration rather than reactive triage.

Increased fire use will necessitate management changes (16). Mechanical fuels reduction could also be used not only for fire containment but also to establish safe-zone anchors to facilitate greater fire re-introduction (8). Large prescribed burns commonly used in Western Australia are possible because a network of these anchors allows 6 to 8% of the forest to be burned annually (16). Australian foresters make substantial efforts to educate the public about the inevitability of fire and its ecological benefits and to build support for fire use and smoke tolerance.

We will not eliminate wildfire, but public support for proactive use of managed fires can help restore millions of hectares of forest ecosystems. ■

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A review of prescribed burning effectiveness in fire hazard reduction

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Abstract. Wildfire hazard abatement is one of the major reasons to use prescribed burning. Computer simulation, case studies, and analysis of the fire regime in the presence of active prescribed burning programs in forest and shrubland generally indicate that this fuel management tool facilitates fire suppression efforts by reducing the intensity, size and damage of wildfires. However, the conclusions that can be drawn from the above approaches are limited, highlighting the need for more properly designed experiments addressing this question. Fuel accumulation rate frequently limits prescribed fire effectiveness to a short post-treatment period (2–4 years). Optimisation of the spatial pattern of fire application is critical but has been poorly addressed by research, and practical management guidelines are lacking to initiate this. Furthermore, adequate treatment efforts in terms of fire protection are constrained by operational, social and ecological issues. The best results of prescribed fire application are likely to be attained in heterogeneous landscapes and in climates where the likelihood of extreme weather conditions is low. Conclusive statements concerning the hazard-reduction potential of prescribed fire are not easily generalised, and will ultimately depend on the overall efficiency of the entire fire management process.

Additional keywords: fuel management; fire management; forest protection.

Introduction

Prescribed burning is the deliberate application of fire to forest fuels under specified conditions such that well-defined management goals are attained (Wade and Lunsford 1989). A wide spectrum of objectives can be accomplished by prescribed fire, including site preparation for tree regeneration, silvicultural improvements, range and wildlife habitat management, control of weeds, insects and diseases, and biodiversity maintenance (Kilgore and Curtis 1987; Wade and Lunsford 1989). It is the reduction of wildfire hazard in protecting forests, wildland resources and infrastructures at the urban interface, which ultimately affects human safety, that remains the main motivation for prescribed burning, in spite of its growing importance as an ecosystem management tool (Haines *et al.* 1998).

The rationale for hazard-reduction burning is clear-cut. Once a fire is ignited, its behaviour is determined by weather, topography and fuels, but management actions to mitigate its negative consequences are restricted to fuels. Current fire fighting technology fails when faced with multiple-fire events, and is not able to cope with wildfires burning under severe weather conditions. According to the review of Hirsch and Martell (1996), it is generally accepted that the suppression capability of ground forces has an upper fireline intensity limit of 3000–4000 kW m⁻¹, and that fire fighting actions are futile beyond 10 000 kW m⁻¹.

Fire intensity is essentially a function of rate of fire spread and the amount of available fuel for combustion (Byram 1959). Prescribed fire decreases the intensity of a subsequent wildfire primarily by reducing fuel loads, especially of the finer elements in the more aerated fuel layers that govern fire spread (Rothermel 1972), but also by disrupting the horizontal and vertical continuity of the fuel complex. Fuel modification from a prescribed-burning treatment is expected to improve directly the probability of successful fire control by reducing fire intensity. In ecosystems where high-intensity fire is not acceptable, the routine use of prescribed fire should change the wildfire regime such that it will be characterised by smaller and less severe fires from both the ecological and economic perspective.

Relationships between fuel accumulation and wildfire activity have been reported in Europe, for both the Mediterranean basin (Rego 1991) and the boreal forest (Schimmel and Granström 1997). Logical reasoning, model simulation and observation all indicate that fire exclusion from the conifer ecosystems of the western USA has led to unnatural fuel accumulations conducive to uncontrollable and highly-damaging wildfires (Van Wagtendonk 1985; Arno and Brown 1989; Keane *et al.* 1990; Brown *et al.* 1994). The so-called fuel/age paradigm (Zedler and Seiger 2000) states that previous fire history controls the spatial pattern of fires in vegetation types with a time-dependent, fuel-driven,

non-random fire regime. For example, fire size in California chaparral is limited by fuel age patchiness (Minnich 1983; Minnich and Chou 1997), and fuel contiguity influences the spatial distribution of fire (Chou *et al.* 1990). Natural prescribed fire programs in conifer forests of the Yellowstone (Sweeney 1985) and Yosemite (van Wagendonk 1995) National Parks have generated fuel mosaics where previous fires act as effective containment lines. Similar patterns occur naturally in the boreal forest of Canada (Amiro *et al.* 2001).

The efficiency of prescribed fire in reducing wildfire hazard is frequently mentioned as a matter of fact, but the basic premise is seldom questioned. However, uncertainty about the protective advantages brought by prescribed burning has been identified by fire managers as an obstacle, albeit minor, to expansion of its use (Haines *et al.* 2001). The meaningful quantification of the impact of fuels on fire regimes is regarded by Schmoltdt *et al.* (1999) as a major research priority. Even though fuel effects are accounted for by current fire behaviour models used in fire management applications, proper quantification of such effects has not been attempted for high-intensity fires burning under extreme weather conditions (Cheney 1996).

Fuel breaks, whose efficiency has been discussed by Agee *et al.* (2000), and prescribed fire are part of complementary strategies, aiming respectively at wildfire containment by fuel isolation and fire behaviour modification by fuel reduction (Pyne *et al.* 1996). It is the purpose of this paper to analyse, as objectively as possible, the premise that prescribed fire is a valuable tool for forest protection and wildfire mitigation, on the basis of a literature review covering different vegetation types and fire environments from North America, Australia and Europe. The economic aspects of prescribed burning have been reviewed by Hesselin (2000) and will not be addressed here.

Fuel reduction assessment at the management level

The effectiveness of prescribed burning at the management level can be determined by effective monitoring, where a systematic process of data collection is used to establish a basis to evaluate and adjust the practice (Van Wagendonk *et al.* 1982). Evaluation by fire management agencies of the effectiveness of prescribed fire in hazard reduction generally concentrates on its effect on fuels. Burning plans usually specify how much and what categories of fuels should be removed, which requires pre- and post-burn assessments.

Several alternative methods can be used to determine pre-burn fuel quantities, including the assignment of standard (Anderson 1982) or custom (e.g. Fernandes and Pereira 1993) fuel models, photo series illustrating known fuel loads (e.g. Weise *et al.* 1997) or fuel hazard classifications (McCarthy *et al.* 1998) that are compared with the current fuel situation being monitored in the field. Indirect procedures to estimate fuel loads resort to descriptors such as vegetation height,

cover and litter depth (e.g. Sneeuwjagt 1973; Armand *et al.* 1993; Finney and Martin 1993), which are frequently measured using line intercept sampling techniques (Van Wagner 1968; Brown 1974). Direct evaluation by destructive sampling methods (e.g. Brown *et al.* 1982) is seldom used by fire managers.

Fuel consumption achievement by hazard-reduction burning can be described or quantified by destructive sampling of the remaining fuel, visual estimates (usually expressed as a percentage of the pre-burn loading), specific photos series for fuel reduction (Scholl and Waldrop 1999), or measurement of post-burn variables such as charred surface percentage, depth of burn, diameter reduction of large woody fuels, and diameter of the remaining shrubs and twigs. Depth of burn, widely used in Canada (e.g. McRae *et al.* 1979), is especially relevant when the forest floor is predominant in the fuel complex. Ryan and Noste (1985) conceived a practical and broadly applicable method using flame length and char depth classes to assess prescribed fire severity that can be used to qualify forest floor consumption. Prescribed fire users in France and Portugal are simultaneously asked for quantitative and qualitative evaluations of fuel consumption during the monitoring process of the practice (Rigolot and Gaulier 2000).

Few examples exist where quantitative information on fuel reduction is translated into classifications of effectiveness, probably because of the natural variability in fuel conditions. In *Eucalyptus* woodland in the Blue Mountains of south-eastern Australia, James (1999) considers that a burn is effective when fine fuel reduction surpasses 50% of the pre-burn quantity and proposes a methodology based on visual estimates of both reduced and created fuel to verify if fuel management objectives are met. Buckley and Corkish (1991) also propose a visual method of rating fuel reduction in thinning slash of *Eucalyptus sieberi* (Table 1). More objective classifications of fuel reduction effectiveness based on post-burn fuel information are feasible and can be developed with the aid of fire behaviour simulators (see next section).

Fuel consumption by prescribed fire is weather dependent, introducing an additional element of variability into the outcomes of fuel management (Omi and Kalabokidis 1998). For example, even though the average surface fuels reduction during an experimental burning program in *Pinus pinaster*

Table 1. Classification of prescribed fire effectiveness based on visual estimates of fine fuel reduction percentages
Adapted from Buckley and Corkish (1991)

Effectiveness class	Reduction (%)		
	Litter	Slash	Shrub
Very good	>50	>75	>75
Good	25-50	>75	25-75
Fair	<25	25-75	<25
Poor	Unburned	<25	Unburned

stands was 90%, a variation of 9–100% was observed between fires (Fernandes *et al.* 2000a). Proper prescribed burning planning can optimise fuel reduction through the use of predictive models that use fuel moisture content and pre-burn fuel loading as inputs (e.g. McRae 1980; Sandberg 1980; Harrington 1987; Brown *et al.* 1991). However, variability in fuel consumption within a site is unavoidable and can be large (e.g. Robichaud and Miller 1999), which means the burn goal may not be achieved in some areas of the overall burn.

Fire managers should also appraise fuel reduction based on area treated, especially when aerial ignition is used to apply fire across a large landscape. According to Wade and Lunsford (1989), it is sufficient to have fuels reduced on 75–80% of a given area, while Wilson (1992) indicates a range from 50% to 90%, depending on fire protection priorities. The target for hazard reduction in Tasmanian moorland is a 70% fuel consumption over 70% of the area being treated (Marsden-Smedley *et al.* 1999).

Computer simulation of prescribed fire effectiveness

The changes induced on the fuel complex structure by a fuel treatment are measurable, and can be quantified in terms of changes in fire behaviour by computer simulation. The BEHAVE fire behaviour prediction system (Andrews 1986) based upon the spread model of Rothermel (1972) is frequently used to predict and compare fuel treatment effects on potential fire hazard, using customised fuel modelling (Burgan and Rothermel 1984) to emulate the modifications undergone by the fuel complex. Users of this approach should be aware of the subjectivity in quantifying post-burn shrub and downed woody fuels depths for the purpose of building a fuel model.

Anderson and Brown (1987) characterise fire behaviour in managed (not specifying the method of treatment) and untreated fuels of common western United States vegetation types. Their BEHAVE simulations for extreme fire weather show post-treatment reductions in fireline intensity between 80% and 96%. Similar figures in the range 80–98% were obtained for southern European pine stands after experimental prescribed fires (Rego *et al.* 1987; Vega *et al.* 1994; Fernandes *et al.* 2000b). When evaluating an actual prescribed fire management program, Fernandes *et al.* (1999) found an average fireline intensity reduction of 98% of the pre-treatment values, allowing wildfire suppression to be undertaken by direct attack with hand tools (Andrews and Rothermel 1982). However, the estimated decrease in fire behaviour can be as low as 10% (Omi and Kalabokidis 1998) due to insufficient impact on the fuel complex because of excessive fuel moisture. These previous results concern the immediate effects of prescribed fire. However, the effect of time since burning can be simulated by dynamic fuel models. For example, in the pine forests found on Florida's coastal plain, difficulty of wildfire control would be moderate to high 5 years after treatment (Brose and Wade 2002).

Empirical Australian models and guides for fire spread in eucalypt forest, derived from experimental fires under relatively mild weather, use a directly proportional relationship between rate of fire spread and fuel load (McArthur 1962, 1967; Sneeuwjagt and Peet 1985). Consequently, they predict that a 50% reduction in fuel load will halve the rate of spread but reduce fireline intensity fourfold.

The benefits of extending the simulations from the plot/stand scale to a landscape scale are obvious. Outputs from the BEHAVE system, combined with crown-fire initiation thresholds, indicate significant decreases in fire hazard at both the stand and landscape levels from the joint application of prescribed fire and thinning in late-successional forests of the north-western United States (Wilson and Baker 1998).

The association of GIS technology with fire behaviour models makes detailed predictions possible at the landscape level. FARSITE (Finney 1998) is a spatial fire growth model that integrates spatial (fuels and topography) and temporal (weather, fuel moisture) data, allowing analysis of the implications of fuel changes under specified ignition and weather scenarios.

Van Wagtenonk (1996) used FARSITE to examine fire behaviour modifications due to fuel-breaks and alternative management practices of surface fuels and crown fuels in the Sierra Nevada of California. Prescribed fire was the most effective technique, and under severe weather conditions reduced the average fireline intensity of a wildfire by 76% and its burned area by 37%, avoiding manifestations of severe fire behaviour. Stephens (1998) compared the effects of 12 different fuel and silvicultural treatments using FARSITE where prescribed burning alone, or in combination with thinning, was the most effective method to reduce fireline intensity.

The most complete example of FARSITE capabilities comes from Finney *et al.* (in press). Two scenarios were tested: no-treatment, and a combination of prescribed burning with tree pruning and thinning. Fire fighting effectiveness was simulated for both cases, and their fire suppression, fuel management, property damage and post-burn rehabilitation costs were estimated. According to the simulation, fuel management did slow fire growth and allowed for quicker fire containment. Estimated costs and net value change of the no-treatment option were estimated to be seven times higher.

Any fire behaviour simulation should consider the effect of prescribed fire that leads to a decrease in wildfire intensity, and consequently to easier suppression and less damage. The passive effect of prescribed burning on wildfire propagation, which assumes that the fuel complex becomes non-flammable, thus preventing fire ignition and spread, can also be explored. After formulation by Gill and Bradstock (1998), this approach has been attempted by Bradstock *et al.* (1998a) on a simulated landscape, relying on a simple spatial model based on percolation theory. The authors conclude that prescribed burning diminishes the average size of wildfires burning during extreme weather conditions only when the

rates of wildfire occurrence are low, and stress the importance of preventing ignitions.

Observed effects of prescribed burning on wildfire behaviour, severity and suppression

Well-documented case studies concerning the fate of wildfires that run into fuel managed areas are useful to fulfil the objectives of this review. A number of examples are available and testify to both the virtues and limitations of hazard-reduction burning.

Tree damage resulting from wildfire occurrence is one of the most used descriptors of the prescribed fire effect. Reductions in tree mortality and crown scorch have been found for *Pinus ponderosa* stands that were treated by prescribed burning 1 year (Wagle and Eakle 1979), 5 years (Pollet and Omi 2002) and 6 years (Martin *et al.* 1988) before the wildfire, when compared with adjacent untreated stands. Weatherspoon and Skinner (1995) showed the importance of previous stand conditions, and indirectly, fuel management activities in the reduction of tree crown injury after extensive wildfires in California conifer forests: all stands with untreated fuels were severely damaged.

Wildfires burning under extreme drought conditions swept across 10 000 ha of the Osceola National Forest in Florida, despite the existence of a regular prescribed fire program (Outcalt and Wade 2000). Nevertheless, pine mortality in recently burned areas (up to 1.5 years) was restricted to 15% in natural stands and 5% in plantations, while it reached 44% and 52% in the same stands, respectively with a fuel age of 2 years or more.

California chaparral burned sites of 12–20 ha in size were successful in containing 11 wildfires at temperatures above 32°C, relative humidities below 20%, and wind speeds higher than 30 km h⁻¹ (Franklin 1988). Regelbrugge (2000) also described how a prescribed burned area in chaparral contributed in protecting a community from wildfire in a wildland–urban interface.

The south-east of Australia provides several examples of the prescribed burning effects on wildfires. McArthur *et al.* (1966) describe how a scrub area burned 1 year before hindered a fire from entering a pine plantation. Four case studies of wildfires burning under conditions of very high fire danger in *Eucalyptus* forest and heathland show that fuel reduction burns up to 10 years old can still influence fire behaviour, even if the best results occurred within 2 years after the treatment (Grant and Wouters 1993). Five case studies are reported by Billing (1981) where property losses were avoided or fire-line intensity was diminished, thus making direct fire fighting attack possible. Rawson *et al.* (1985) found evidence of wildfires stopped or slowed by previous prescribed fires, improved fire control operations due to the existence of fuel-reduced areas, effective protection of assets, and less overall demand for fire fighting resources. These benefits extended through 5 years after the treatments.

McCarthy and Tolhurst (2001) present an in-depth assessment of the effectiveness of fuel reduction burning in public land across the state of Victoria in Australia. Suppression of 11% of the wildfires occurring in 1990–1997 was positively affected by the practice, with fuel hazard level (or time since last burn) and fire danger index being critical regarding the probability of a previous prescribed burn slowing a head-fire. Obvious effects in wildfire propagation were observed in areas treated no more than 2–4 years before, but the assistance to fire suppression generally ceased after 10 years. Fire spread delays for a given fuel hazard level are also increasingly less likely as fire weather becomes more severe.

Valuable assistance to fire control is attributed to prescribed fire during the less severe phases (estimated fireline intensity in the 1000–7000 kW m⁻¹ range) of the extensive Dwellingup fire of 1961 in the *Eucalyptus marginata* forest of south-western Australia (Peet and Williamson 1968). During the major run of the same fire, with a fireline intensity in excess of 15 000 kW m⁻¹ (Peet and Williamson 1968), the fire dramatically changed its behaviour and did not affect the tree crowns as it crossed an area that was burned 2 years before (McArthur 1962). Underwood *et al.* (1985) describe nine selected wildfires in south-western Australia whose direct attack was not possible or failed, but that were only controlled after entering areas treated up to 4 years before. Previous prescribed fires affected the outcomes of a wildfire in a *Pinus pinaster* plantation in the same region (Burrows *et al.* 2000): intensity, difficulty of control, and tree damage were higher where fuel loading was greater. McCaw *et al.* (1992) report extensive fire propagation in 5-year-old shrubland in south-western Australia under conditions of extreme fire weather that generated fire intensities estimated at 20 000–40 000 kW m⁻¹; a delay in fire spread and actual vegetation patches remaining unburned were observed in 5-year-old fuels, but not in fuels older than 8 years.

In Europe, where prescribed fire programs are more recent and localised, available information is scarce. In *Pinus pinaster* stands in Portugal, Silva (1997) describes how three wildfires were affected by burned buffer zones established in the previous winter. Fire behaviour was visibly reduced by the treatments, allowing easy containment in one of the cases. Observations by the authors in *Pinus pinaster* stands in Portugal where prescribed fire had been carried out 4 years before include a stand-replacement fire that was turned into a non-lethal surface fire, and a crown fire that went through a pole-sized stand without any noticeable reduction of intensity.

Some well-documented case studies are available for southern France. Rigolot (1997) provides six examples of wildfires in the eastern Pyrenees that ran into shrubland areas that were prescribed burned between 1 month and 7 years before; the efficiency of the treatment was variable and seemed to be affected by wind speed, size of the wildfire, and available suppression forces. Lambert *et al.* (1999) assessed the efficiency of fuel-breaks, including those maintained by

periodic burning in combination with grazing or mechanical treatments. The authors reported 10–100-fold reductions in fireline intensity for a wildfire crossing a fuel-break, and indicated a fuel loading of 1 t ha^{-1} as the upper threshold where a wildfire under extreme weather conditions (including wind speeds up to 90 km h^{-1}) will not be stopped by a fuel-break in the absence of suppression.

Effects of fuel reduction on the wildfire regime

Fire regime can be defined as the nature and severity of fire occurring over long periods (Brown 2000). The available examples relate essentially to the effects of prescribed fire on the size component of the fire regime, and come from parts of the United States and Australia with extended prescribed burning programs. Wright and Bailey (1982) refer to studies by several authors indicating reductions in the area burned by wildfires in the *Pinus ponderosa* forests of the western United States as a result of prescribed burning programs. Fires occurring in fuel-reduced areas also tend to be smaller, less damaging to trees, and lower in fire suppression expenditures.

Davis and Cooper (1963) found that the number, but especially the size, of wildfires in the coastal plains of the south-eastern United States increased with time since the last hazard-reduction burn: 7% of the total forested area with fuels older than 5 years burned each year, in contrast to a figure of 0.1% where fuel accumulation time had not reached 5 years. The effect of prescribed burning within the same region has been analysed by comparing wildfire activity in treated and non-treated areas (Martin 1988, cited by Koehler 1993): 91.5% of the area burned by wildfires larger than 40 ha occurred where prescribed fire had not been used during the previous 3 years, while the average size of a wildfire was 8.5 ha in areas treated within the last 3 years and increased to 25.2 ha in untreated areas. An estimate was made that prescribed burning saved more than 4500 ha of forest and decreased fireline intensity on 2385 ha.

Koehler (1993) analysed fire statistics in a portion of central Florida from 1981 to 1990. He concluded that prescribed fire programs that have been active for a sufficient time are reflected in less and smaller wildfires on average. Data also showed minor fluctuations in wildfire acreage from year to year, suggesting that prescribed fire attenuates the behaviour of subsequent fires that might occur under severe fire weather.

Mercer *et al.* (2000) examined the relationship between wildfire activity in counties of Florida during the particularly severe year of 1998 and the number of burn permits, a surrogate for prescribed fire activity. In contradiction with the above-mentioned studies, little statistical evidence was obtained that prescribed fire reduces wildfire area. Smaller and less numerous burn operations were associated to the occurrence of larger wildfires, but the authors have considered such result not conclusive, since a lower number of prescribed fire permits may be issued in severe wildfire years.

The results were even less demonstrative of a prescribed fire effect when the approach was extended to the 1995–1999 period by Prestemon *et al.* (2002), who question the adequacy of the permits to describe the amount of prescribed burning and suggest a finer spatial scale of analysis.

According to Cheney (1996), prescribed fire has been so effective in reducing the wildfire threat to some regions of Australia that local inhabitants have developed a false sense of security. More than 90% of the wildfires in south-western Australia remain below 10 ha and large fires occur only under extreme weather situations. As a consequence of the emphasis that has been put in the prescribed burning practice since the early 1960s, most large wildfires occurred where the use of prescribed fire is less substantial (Sneeuwjagt 1994). A valid counter argument is that the two first-mentioned effects can be affected by efficient fire suppression resources, since early detection and rapid initial attack are common features of the fire management strategy in western Australia (Underwood *et al.* 1985).

In the opinion of Meredith (1996), prescribed fire is more effective in south-western than in south-eastern Australia. Nevertheless, the statistics for southern New South Wales in the period 1980–1992 are also favourable (Good 1996): the average size of a wildfire burning in treated areas with less than 3 years was 302 ha, against 584 ha outside treated areas, and only 15% of the wildfires occurring on prescribed fire areas had grown to more than 50 ha.

Limitations and constraints to prescribed fire effectiveness

Weather and fuel considerations

The previously mentioned study by McCarthy and Tolhurst (2001) is expressive of the limitations that extreme fire weather and fuel re-accumulation impose on the effectiveness of a prescribed burn program. A very small percentage of the total number of all wildfires accounts for the majority of the burned area (Strauss *et al.* 1989) and those fires are driven by synoptic-scale weather patterns (Schmoltdt *et al.* 1999). Jasper (1999) states that 95% of the fires that destroyed property occurred on days when the fire danger was very high or extreme. Prescribed fire impacts the behaviour and effects of large wildfires, but it is unlikely that the fuel effect will override extreme weather conditions to the extent of actually inhibiting fire spread. However, the critical importance of weather can be easily underestimated when the emphasis of management is placed on fuel modification (Bradstock *et al.* 1998a).

Simulations of surface fireline intensity and crown fire initiation in western Canadian subalpine forests have attributed a relatively minor role to fuel in comparison to weather (Bessie and Johnson 1995). On the contrary, simulations for boreal mixedwood forest of eastern Canada, where weather is generally more moist and vegetation variability among stands is

high, show that fuels are the driving force in fire behaviour (Hély *et al.* 2001). In opposition to a well-established belief (e.g. Rothermel and Philpot 1973; Sapsis and Martin 1994), it has been shown that large chaparral fires in southern California do not depend on the availability of old fuels for their propagation (Dunn 1989; Keeley *et al.* 1999) nor are they stopped by a landscape mosaic of different fuel ages (Zedler and Seiger 2000; Keeley and Fotheringham 2001). Similarly to chaparral, most subalpine (Bessie and Johnson 1995) and boreal forests (Johnson *et al.* 2001) in Canada are closed-canopied vegetation types characterised by a fire regime of large and inevitable stand-replacing crown fires induced by the vertical and horizontal fuel continuity and triggered by dry periods.

The previous paragraph leads to the conclusion that the fuel/age paradigm is a simplification, and that the hazard-reduction effectiveness of prescription burning will vary by ecosystem (or fuel type) and according to the relative impacts of fuels and weather on fire behaviour. Because fire behaviour increases in a non-linear fashion with the decrease of fuel moisture and the increase of wind speed, which additionally vary in a much wider range than fuel properties, the influence of these factors on fire behaviour will increasingly prevail over the effect of fuel characteristics in more severe weather scenarios. Prescribed burning will be less effective in regions that have higher likelihood of experiencing strong winds during drought periods, because such combination is conducive to extreme fire events in intensity and extension (Schmoldt *et al.* 1999).

Longevity of the prescribed fire effect is conditioned by the intrinsic nature of vegetation, sooner or later, regaining its former fuel loading and structure. Fuel dynamics knowledge is used to define the prescribed fire return interval and the burning effort required to reach a management objective (e.g. to maintain fuel loads below a given hazard threshold). However, post-treatment recovery can be so fast that fuel management may be futile or even counter-productive in some vegetation types (e.g. Fensham 1992). Fuel dynamics can be exacerbated by a number of factors, namely the amount of remaining fuel and newly created fuel (i.e. conversion of live vegetation to dead fuel, post-burn litter fall), changes in vegetation composition such that it becomes more flammable (e.g. invasion by grass or weed species), and post-burn reduction of the decomposition rate.

Litter hazard is commonly re-established within 2–5 years after prescribed fire (Sackett 1975; Van Wagtenonk and Sydorik 1987; Fensham 1992). Nevertheless, the overall benefits of prescribed burning, namely in avoiding crown fire or substantially reducing the potential for its occurrence, should persist for longer periods, since the understory vegetation layer build-ups at a lower rate. Reduction in the amount of fibrous loose bark is important in some *Eucalyptus* species to preclude the development of crown fires and reduce airborne firebrands lofted ahead of the fire front (McArthur 1967);

the effects of prescribed fire on this fuel component can be of long duration (Tolhurst *et al.* 1992).

Fireline intensity will undoubtedly be decreased by prescribed burning compared to a no-treatment scenario so long as fuel loads remain below the pre-treatment values. However, early claims that rate of spread increases with fuel load (e.g. McArthur 1962), are not supported by more recent studies (Gould 1991; Cheney *et al.* 1993; McAlpine 1995; Burrows 1999), which points to a short-lived effect of prescribed burning on this fire parameter, probably disappearing as soon as the fuel complex regains its pre-burn structure. Experimental studies (Cheney *et al.* 1998) designed to clarify the effect of time since last fire and fuel loading on fire behaviour under an extended range of burning conditions are being undertaken in dry eucalypt forest in south-western Australia.

Spatial considerations

The size, shape and spatial arrangement of the treatment units, including their location in relation to fuel breaks (Agee *et al.* 2000), can strongly affect the efficiency of the prescribed fire treatment at the landscape scale. The hazard reduction effect brought by discrete fuel treatments to specific stands may be too small and/or too fragmented to have any impact on large fires (Omi and Kalabokidis 1998).

The spatial pattern of hazard reduction burning can be quite varied, comprising treatments dispersed in the landscape, extensive application to large areas, or strategic and more intensive use in order to link or expand discontinuities such as fuel breaks and non-flammable areas. In the western United States (Finney 2002) and in Canada (McRae and Flannigan 1990), prescribed fire is commonly applied in units of 100s to 1000s of hectares. Maximum size of the burn units can reach 8000 ha in Australian eucalypt forest (Grant and Wouters 1993), 300 ha in southern France shrubland (Rigolot 1997), or 30 ha in pine stands of Portugal (Fernandes *et al.* 1999).

The hazard-reduction advantages of large-scale prescribed burning are not proven and some authors are of the opinion that burning in strategic small areas creates more effective barriers because the percentage of area burned is higher and the amount of residual fuel is lower (Grant and Wouters 1993; Rawson *et al.* 1985). For vegetation types dominated by crown-fire regimes, Keeley (2002) suggests intensively managed buffer zones (including prescribed burned areas) in strategic locations, especially in the wildland–urban interface. However, in fuel types prone to long-distance spotting, the benefits of prescribed fire on a broad area basis are apparent: sufficiently large treatment units will provide landing spots for most firebrands, reducing their ignition potential and the likelihood of developing into intense fire fronts, as well as reducing production and lofting of firebrands when the main fire front actually propagates in the treated area. Simulations with FARSITE suggest that disperse and small treated areas are preferable to network-type treatments,

because shorter distances will result between individual fuel-reduced areas thus limiting wildfire growth more effectively (Finney *et al.* 1997). According to Loureiro *et al.* (2000), maximum landscape fragmentation (a surrogate for fuel discontinuity) is achieved by a compromise between the number and the size of prescribed fire units.

Selection of treatment areas currently relies on combined functions of several factors, such as values at risk, ignition potential, suppression capability and fire behaviour potential (Sneeuwjagt 1998). Other constraints are listed in the next section. According to Finney (2001), such approaches will likely originate arbitrary or random spatial patterns with a poor influence on wildfire growth. Based on fire shape and relative fire spread in treated and untreated areas, Finney (2001) gives a set of equations to optimise the width and length of a rectangular treatment unit such that it maximises the delay in the propagation of a wildfire. After extending the same reasoning to a landscape level, the author concludes that feasible and effective spatial arrangements of prescribed burning should result in treatment units that partially overlap in the direction of fire spread. A promising automated method to optimise fuel treatment patterns in real landscapes is under development (Finney 2002).

Operational, social and ecological constraints

Prescribed burning programs are strongly constrained by a number of factors, including inadequate funding. Bradstock *et al.* (1998b) mentions other constraints such as suitable weather for burning, and favourable landscape in terms of topography and vegetation continuity. Meredith (1996) stresses the importance of environmental heterogeneity and gives the example of western versus eastern Australia: drier and more predictable weather, milder topography, and relatively uniform forests in south-western Australia allow larger, safer, and more effective burns that can be conducted more times per year. Liability risks and the necessity to comply with environmental protection, smoke management and air quality regulations are nowadays an important restriction to prescribed fire activity in both the United States (Haines *et al.* 1998, 2001) and Australia (Underwood and Sneeuwjagt 1993).

The opportunities to carry out prescribed burning operations are greatly reduced by the above-mentioned restrictions, and thus can compromise hazard minimisation in fire-prone regions. For example, in the urban-wildland interface of Sydney, Australia, 27% of the area would require annual treatment if probability levels of uncontrollable fire were to be reduced to 10 days per year (Bradstock *et al.* 1998b). The number of available days for burning is quite variable from year to year (e.g. Gill *et al.* 1987); it can be increased by broadening the prescription to hotter and drier conditions, but several problems may arise, including higher probabilities of escaped fires and property damage. According to

a survey conducted in western United States, weather is by far (39% of the respondents) the most important reason for cancelling prescribed fires, followed by smoke management and air pollution concerns (18%) (Barrett *et al.* 2000).

Prescribed fire planning often gives ecological considerations a secondary role, and the consequence is that fire managers can assume a successful fuel reduction operation as a burn that fulfills ecosystem management goals (Bennett and Kunzmann 1992). Conflicts between hazard-reduction burning and conservation values should be negligible in ecosystems with a recurrent history of low-intensity surface fires (e.g. Haase and Sackett 1998; Sackett and Haase 1998; Ward 1998; Barnett 1999), but not where a natural fire regime characterised by high-intensity fire is replaced by more frequent, smaller and less severe fires (Whelan and Muston 1991). Given the absence or scarcity of results from long-term studies on the ecological effects of prescribed fire regimes, methodologies based on biological indicators have been proposed to reconcile protection and conservation objectives (Gill and Bradstock 1994; Burrows and Friend 1998; Gill and McCarthy 1998), but such compromise is not always possible (e.g. Morrison *et al.* 1996; Bradstock *et al.* 1998c).

Conclusion

The hazard reduction benefits of prescribed fire are easily demonstrated by fire behaviour theory, through observation and measurement of post-treatment fuel changes in experimental or operational burns, and by computer simulation at the plot, stand, and landscape levels. Despite their limitations, the existing fire behaviour models, linked with fire effects and fuel dynamics models, provide a useful framework to predict and evaluate the outcomes of fuel management strategies, select alternative treatment methods, and plan the fuel treatments in time and space.

The operational effectiveness of prescribed fire inferred from case studies is largely anecdotal, and most of the examples of success that are available refer to recently (up to 4 years) treated areas. A wildfire is an unplanned event, which implies uncertainties regarding fuel characteristics, weather and fire behaviour, as well as the existence of interactive effects. Analysis of hazard reduction effectiveness based on well-documented case studies of wildfire behaviour, severity and suppression difficulty as modified by burned areas is thus limited in the conclusions that can be drawn. This stresses the need for replicated studies of high-intensity fire behaviour in field experiments.

Analysis of modifications in the fire regime induced by prescribed burning are currently the best way to evaluate the practice, even if they do not allow direct statistical confirmation. Positive changes brought by long-term prescribed fire programs are undeniable, but it is quite difficult, if not impossible, to isolate the protective effect of the treatment from the whole fire management process.

The amount of land that can be subjected to prescribed fire is greatly restricted by several operational and ecological issues, thus making a fire management approach difficult based solely or predominantly on prescribed burning. The higher incidences of unwanted ignitions are associated with areas where human pressure and residential development are also high, posing additional social constraints and operational difficulties on the use of fire. Nevertheless, rather than burning as much as possible, it is more important to carefully select the treatment locations. Simulations of fire growth or percolation in landscapes containing different fuel treatment configurations in terms of size, shape and spatial arrangement can give valuable insights into the delineation of more effective prescribed burning programs. Sound, well-established methods to design the spatial patterns of treatment application are still missing, and optimisation of the spatial arrangement of prescribed fire clearly requires further research.

Quantification of the influence of prescribed fire on large wildfires remains elusive, but the existing evidence supports the conclusion that recently treated areas do limit the spread of a fire and will result in a less homogeneous post-burn landscape. It is clear that prescribed fire moderates wildfire severity and can benefit wildfire control operations in various ways, by increasing the safety of the personnel involved in suppression, decreasing the quantity and type of fire fighting resources (e.g. ground crews instead of aircraft), changing the overall suppression strategy (e.g. direct attack instead of indirect attack), reducing the risk inherent to the burning-out operations that are used in indirect attack, lessening the amount of mopping-up, or simply providing better access and anchor points for suppression actions.

The best results of prescribed fire application (and indeed of other fuel management options) are likely to be achieved in regions less prone to experiencing extreme weather conditions, and where wildfire propagation is *a priori* constrained by landscape and land use diversity, and by natural or artificial obstacles. The spatial pattern of fuel treatment is also less critical in those situations. Since prescribed burning reduces but does not eliminate the threat posed by wildfires, mitigation of their undesired effects should rely on an integrated approach that combines prevention of human-caused fires, efficient fire detection and suppression, and adequate stand and fuel management practices.

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Controlled Burning as a Dual-Purpose Tool of Forest Management in New Jersey's Pine Region

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Subject to frequent and devastating fires the New Jersey pine region is one of the "hot spots" of the Northeast. Scrub forest with tall resinous-leaved shrubs and heavy accumulations of duff present dangerous fuel conditions. Long fire seasons, few obstructions to wind and soils that dry readily add to the hazard. Disastrous fires as a consequence are all too common. Furthermore, favored by protection, oaks and other low-value hardwoods have encroached on pine land where they seldom attain sawlog size. Controlled burning properly applied and safeguarded offers an effective tool both for reducing fuel and for favoring pine over oak.

CONTROLLED burning, sometimes called prescribed burning, is not a new practice in southern New Jersey. It has been used for protection purposes on some areas, particularly on the Lebanon State Forest, for 20 years. Studies of its use as a silvicultural tool were started on the Lebanon State Forest in 1936. Results of this latter work were published in 1945 (3). The practice lends itself so effectively to an integration of the uses of fire for silvicultural and protection purposes that in recent years as much as 1,000 acres have been burned annually under prescribed methods on the Lebanon State Forest.

This prescribed use of fire has aroused considerable interest among private timberland owners in southern New Jersey with the result that the State Conservation Department is now supervising controlled burning on some private lands. Accordingly, after 12 years' testing of the use of fire as a silvicultural tool, and some 20 years of its gradually increasing use for protection purposes, the authors believe it is time to report on controlled burning as a dual-purpose tool of forest management in the Pine Region of New Jersey.

The original upland forests in the Pine Region consisted of open stands of large pitch and shortleaf pines. Years of heavy cutting and hot wild fires have greatly favored sprout oaks to the detriment of pine, many of which are now deformed by fire. Thousands of acres now produce nothing of value; the estimated timber cut in 1946 was equivalent to only 1 cord from every 14 acres of woodland. The problem is to convert these deteriorated forests to pine stands of seedling origin.

The more rapidly growing pines do grow to

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sawtimber and piling size; the oaks rarely produce more than cordwood (3, 5). Several methods of conversion have been tried. Planting pine seedlings followed by cleanings to insure dominance over oak sprouts was tried (5) but it was soon realized that this was costly; that natural reproduction methods might be cheaper and at the same time result in more desirable stands. Accordingly, studies were made on the use of machinery and on the use of controlled burning in preparing seedbeds for natural regeneration of pine. Supplemental studies were made on methods of cutting, slash disposal, and control of advance hardwood growth.

The total results show that pine seedlings can be established by planting or by preparing a seedbed either with machines or by controlled burning. Planting costs at least \$15 to \$20 per acre. No reduction in fire hazard is obtained by this method, however, and at least two cleanings are probably needed to insure a good stand of pine. The same approximate cost applies to the use of machinery; the same number of future cleanings would be needed.

The use of controlled fires greatly favors the establishment of pine reproduction and the control of less valuable hardwoods. Although earlier results were previously published in detail (3), a summary of recent data is given here to provide perspective on the silvicultural phases of controlled burning. Table 1 summarizes the mortality and basal scarring resulting from several prescribed burns. These data illustrate the fact that oak is much more susceptible to controlled fire than pine. They thus indicate that controlled burning can be used to increase the ratio of pine to oak in this type.

The effect of controlled fires on pine seedlings and their establishment is shown in Table 2. The data substantiate the obvious fact that burns are extremely destructive to the small seedlings already present. Of more significance, however,

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is the fact that seedbed preparation through controlled burns results in the establishment of much new pine reproduction.

The increased pine reproduction, established as the result of controlled burns, will need a period of protection to allow the pines to reach 2 inches d.b.h. After that period, further use of controlled fire will aid in the maintenance of high proportions of pine through selective killing and damage to competing oaks. The spacing of periodic burns should then be close enough so that oak reproduction remains susceptible to killing by fire throughout the pine rotation. Because the susceptibility of the hardwoods decreases rapidly as their height increases beyond 4 feet, fire should be used as often as necessary to prevent any appreciable number from growing to greater size.

The sequence of operations over a rotation, but beginning in reproduction stands of oak and pine, should be approximately as follows for silvicultural purposes:

1. Heavy cuttings of oak sprouts until pines

TABLE 1.—MORTALITY AND BASAL SCARRING OF PINES AND OAKS RESULTING FROM SEVERAL CONTROLLED BURNS¹

D.b.h. (Inches)	Mortality		Basal scarring	
	Pine (From 10 annual burns)	Oaks (From 6 annual burns)	Pine (After 10 annual burns)	Oaks (After 6 annual burns)
	Percent	Percent	Percent	Percent
Ingrowth	16	100	19	—
1	3	12	8	49
2	0	2	6	32
3	0	1	0	16
4-6	0	0	0	9
Over 6	0	0	0	0

¹Data are from the experimental areas described in the earlier publication (3). Mortality shown is the difference between that on the burned areas and that on the controls. Pines are pitch and shortleaf. Initial d.b.h. is used for mortality, and final d.b.h. of surviving trees for basal scarring. Ingrowth includes those trees reaching 0.6 inches in diameter during the study.

TABLE 2.—THE EFFECT OF VARIOUS SCHEDULES OF CONTROLLED BURNING ON PINE SEEDLINGS AND THEIR ESTABLISHMENT

Number of burns 1937-46	Number of growing seasons since last burn	Percent change in number of seedlings, 1937-46, by height classes of—			
		0.0-1.5 feet	1.6-3.5 feet	3.6 feet or more	All
3 to 10	1 or 2	+95 to +393	-93 to -100	-33 to -80	+50 to +188
2	5	+516	-75	-60	+362
0 (Control)	43	+9	+11	+114	+19

are 2 inches d.b.h.

2. Periodic burns after pines are 2 inches in diameter and until harvest cuttings are made. These burns will help keep the oaks under control and keep a crop of pine seedlings on the ground. Thinnings and improvement cuttings might also be undertaken during this period as markets permit, particularly in stands where the oaks, because of insufficient cleanings, have grown to sizes where mortality by controlled fire cannot be expected. In case there is no market for these products, girdling or poisoning of the hardwoods is a desirable practice.

3. Harvest cutting using a method resulting in an even-aged stand.

4. Complete protection from fire until the new stand is 2 inches d.b.h.

Partly because of the silvicultural effects, controlled burns are recommended at 4- to 5-year intervals in oak-pine stands 20-60 years old. Under proper conditions, these would cost no more than \$1 to \$1.50 per acre over a rotation except for small areas that are more costly to burn. One cleaning may be sufficient. Total cost including this one cleaning should not exceed \$4 per acre over a rotation, excluding taxes, interest, and other administrative costs that would be no more than under other silvicultural systems. The results so far obtained from studies indicate that the stands would have a much higher percentage of pines where controlled burning is used than under the other systems. In addition fuel accumulations are periodically reduced under prescribed burning so that loss by chance fires is improbable.

Silvicultural measures are of little use if fire protection is ineffective. Fires in southern New Jersey have frequently burned 1 to 2 percent of the area, and in the worst years much more. A major advantage of controlled burning is that it is not only an effective tool for use in converting rundown stands to seedling pine

stands, but is an aid to fire protection as well. This is self-evident; for if the litter of the forest floor is consumed by these light winter fires at periodic intervals, there will be less danger of chance fires gaining headway in the intervals between controlled burns. Controlled burning, however, should be considered only as a supplementary measure in forest fire control. In no wise is it a substitute for organized fire protection. Its effectiveness as a supplement is illustrated by the following case history.

On April 20, 1946, at 11:30 a.m., a spark from a freight engine started a fire near New Lisbon, New Jersey. The fire danger that day was class 5 on the Appalachian meter (model 5-B). The local towerman detected the fire at 11:48 a.m. and at 11:58 a.m. the first warden and two men arrived. These first three men backfired a sand road within 500 feet of the starting point of the fire, were unable to check the head fire, and had to fall back. Three wardens and 14 men tried to hold a two-lane hard-surface road, 950 feet from the first sand road, by backfiring. As the head fire approached, spot fires were set as much as 300 feet beyond the road, and the line was lost. At 1:15 p.m. the head, 150 feet wide, hit another hard-surface road 1,500 feet beyond the second road. The third road was also backfired and 115 men with three fire trucks were stationed along it. Thirty spot fires were, however, set beyond the road in thick undergrowth unburned for 20 years; although within 100 feet of the road, not all of these were suppressed. Some built up and the fire passed on to jump a swamp and creek 350 feet away.

The next chance to stop the main head was on a sand road more than a mile beyond the point where the fire had hit the creek. In driving toward this road, the head again crossed a creek. Two wardens, 35 men, and one fire truck tried to hold this road by backfiring and extinguishing the "carry-overs." Although about 100 spot fires were suppressed, 15 to 20 fires, starting 150 to 250 feet beyond the sand road, built up new heads and this line was lost. Over 9,000 feet beyond this point was the boundary of the Lebanon State Forest. Along the boundary was a forested firebreak on which the surface fuels had been reduced in past years, largely through controlled burning. The head fire struck this line on a $\frac{3}{4}$ -mile front between 5 and 5:30 p.m., setting spot fires as much as

1,200 feet ahead. Twenty-four men and two fire trucks were stationed there. The head fire was stopped; the spot fires, occurring mostly on control-burned ground, were extinguished; and this line was held.

Killing damage was confined on the state forest to less than half an acre. The contrast between the damage on the two sides of the boundary line was very striking; it illustrated the great difference between the results of controlled fire and wild fire (Fig. 1). This difference lies essentially in the fact that light winter fires, when properly used, reduce the fuel continuity on the ground and favor a closed overwood. Periodic severe fires, on the other hand, promote a continuation of hazardous conditions by keeping the overwood open, while the stems killed by the last fire and the resulting sprouts of trees and shrubs accumulate. These in a few years build up a good vertical continuity of fuel leading to the tops of the tallest surviving pines. Part of the total area covered by the 1946 fire had suffered from severe fires twice before since January 1938 and the fuel conditions were exactly as described above. Partly because of the periodic recurrence of such fires with their production and maintenance of hazardous conditions, the authors believe that controlled burning should become a fundamental part of the management of the South Jersey Pine Region.

The New Lisbon fire provided an excellent example of the value of controlled burns in aiding the suppression of severe fires that occur on days of high danger. It aroused new interest in using controlled burning as a management tool for both protection and silvicultural purposes.

WHY CONTROLLED BURNING IS RECOMMENDED

For fire protection.—Controlled burns reduce the thick mats of duff and the dense shrubby understory. Thus much of the fuel is removed, and protection from severe fires is made easier. It should be clearly understood, however, that the protection offered is relative and not absolute. The need for fire suppression forces is not eliminated, but their work is made more effective.

For silvicultural purposes.—Light winter fires may be used to improve the forests by favoring the pines. The burning prepares a suitable seedbed for the natural reproduction of pine and checks the development of hardwoods (3).

Ecological succession provides another argument for controlled burning. If *all* fires were excluded for a long enough period, the pines would be eliminated for all practical purposes. The forest would then be formed of the climax type of less valuable hardwoods which, incidentally, would have a far greater fire hazard than well stocked stands of pine.

WHERE CONTROLLED BURNING MAY BE USED

The Region.—Controlled burning in New Jersey should be limited to the Pine Region in the southeastern part of the state. It should *not*, in the light of present knowledge, be used in the Delaware Valley or in northern New Jersey (3) where the soils are of good quality and support stands of yellow-poplar, sweetgum, pin oak, red oak, and similar species. These good sites usually have a high population of earthworms and other soil fauna that are responsible for the rapid disintegration of dead leaves and the formation of a mull type of humus. Thus the organic debris usually does not accumulate there in amounts sufficient to create a severe fire hazard.

The upland sites in the Pine Region are quite different. Their dry, sandy, acid soils grow pitch and shortleaf pines in mixture with oaks (scarlet, black, chestnut, and white) of low quality. In these soils earthworms and other soil fauna characteristic of mull humus are seldom found, even in areas long unburned. Earthworms must have abundant moisture (10), which the upland soils in the Pine Region do not provide. Soil acidity may be another limiting factor. Lutz (4) shows that the pH of some of these soils ranges from 3.46 to 5.14. These values are well below the 5.6 to 8.3 at which earthworms may occur or the 7.0 to 7.8 at which they are most abundant (9, p. 337).

Because of the absence of these life forms and the low bacterial population, fungi are chiefly responsible for the disintegration of forest litter, and the disintegration is very slow. Litter accumulates on the surface, often to a depth of 4 inches on areas unburned for several years. Such blankets of duff materially increase the fire hazard.

The applicable sites.—Past studies indicate that controlled burning can be used successfully on all upland sites within the region. The treatment is apparently beneficial also in the pine swamps, but under no circumstances should controlled burning be attempted on the true

swamp sites that support stands of white-cedar and swamp hardwoods (2).

The applicable stands.—The use of controlled burns will often be limited by the predominance of small stems in the stands. On upland sites stands where most of the trees are under 2 inches in diameter at breast height should not be burned. Pines over 2 inches are not injured by light fires. Oaks larger than 2 inches are easily scarred, but such damage is considered of little importance in this region because of the limited potentialities of the hardwoods.

Lowland sites have a denser understory of "harder-burning" shrubs (sheep-laurel, leather-leaf, bayberry) than upland areas (blueberry, huckleberry), so that fires generally burn with greater intensity and may injure pines up to 4 inches in diameter. For this reason lowland sites should not be burned unless the dominant pines have diameters of at least 4 inches at breast height.

It is important that all areas be carefully examined before burning. In appraising the probable effects of controlled fire, it is generally unnecessary to consider suppressed stems of either hardwoods or pines.

METHODS OF BURNING

Controlled burning should be attempted only under the direct supervision of an experienced forester or fire warden.³ The objective should be a light fire with flames so low that a man can readily walk through them, that is, with flames mounting on the average not more than a foot or two above the ground. Such a fire will not consume all the debris on many areas, but will materially reduce its depth. Whether the fire is set with or against the wind depends on the fuel moisture conditions and the wind velocity.

Frequency.—The frequency of burning depends on the degree of protection desired. For maximum protection of improved property, burns at 1- or 2-year intervals are recommended. For developing a wide firebreak, burning at 4- or 5-year intervals may be sufficient on upland sites. However, it should be noted that where large fuel accumulations have developed several controlled fires may be needed to reduce the duff gradually to desirable proportions. In such places the first few controlled fires may have to be at 1- to 3-year intervals.

³State law requires that all burning be done under permit from the New Jersey Forest Fire Service.

When to burn.—Controlled burning should be limited to the winter months. The period between Christmas and March 1 usually offers the best conditions, because changes in fuel moisture are then relatively slow. At other times fuels dry too quickly, and a light fire may rapidly build up into a severe one.

Even during the recommended period there are occasional days when the danger will be too high, particularly for burning areas that have thick layers of oak leaves. On such areas burns

should be limited to days that rate a high class 1 or low class 2 on the Appalachian danger meter (model 5-B). Areas that have been long unburned, and on which the fuel accumulation is heavy, should be control-burned when much of the debris is too wet to burn readily; but since litter dries from the surface downward, the proper time can be chosen by experienced personnel.

Present information indicates that the proper conditions for winter burning are as follows:

Average depth of duff	Oak-pine and pine-scrub oak areas where oak leaves predominate in the duff	Upland pine stands with duff composed chiefly of pine needles
<i>Inches</i>	<i>Danger class</i>	<i>Danger class</i>
3 or more	High class 1	Low class 2
1 to 2	Low class 2	High class 2
Less than 1	High class 2	Low class 3



FIG. 1.—Adjoining stands on the boundary of the 1946 New Lisbon fire: A, this stand, control-burned at 2- or 3-year intervals as part of the firebreak on the Lebanon State Forest, helped to stop the forest fire; B, a stand on private land burned by the fire.

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The proper conditions for controlled burning occur on 30 to 40 days during the usual winter. During the winter of 1946-47, for example, there were 38 days when controlled burns could have been made. Of these, 31 were working days.

Speed of firing.—How large an area should be fired at one time depends on two main factors: (1) the burning conditions and (2) the boundaries of the area. On blocks bounded by roads or swamps more fire can be set with safety than where the boundaries are narrow raked or plowed lines. For example, in burning one 90-acre tract bounded by roads and swamps, over a mile of fire was set at one time by three men; whereas the same men in burning narrow fire-breaks (or safety strips) would frequently have only 100 to 200 feet of fire burning at one time. On areas with good boundaries and under favorable conditions fire may be set almost as fast as a man can walk.

COST OF CONTROLLED FIRES

The cost of controlled burns varies with several factors: continuity of fuel; size and shape

of area; type of boundaries; burning conditions; and the experience, judgment, and availability of personnel. The cheapest controlled burns are obtained when (1) there is a continuity of fuel on the forest floor, so that a fire will spread across the area; (2) the area is of such size and shape that a minimum amount of firing per acre is necessary; (3) the area is bounded by wet swamps or roads free from litter, so that no line preparation and a minimum of patrol are necessary; (4) the firing can be made with the wind; and (5) personnel with adequate experience and good judgment are available.

The costs vary considerably (Table 3). For example, the burning of safety strips (8), which adjoin some roads on the South Jersey state forests, is an expensive form of protection, often costing up to \$1 per acre burned. There are several reasons for this high cost.

1. Lack of natural boundaries. The road serves as one boundary, but on the woods side a narrow line about a foot wide is raked. The preparation of this line often accounts for half



the total cost, and the firing work is slowed by the need for seeing that the fire does not cross the raked line.

2. Limited width of the strips. Narrow strips, 25 to 200 feet wide, are expensive to burn because the fire makes a short run, and more firing is needed per unit area.

3. Lack of fuel continuity. The safety strips have been burned at 1- to 3-year intervals, usually for over 10 years, and present fuels are scattered. The dead leaves are blown into piles against some obstruction such as a clump of shrubs, and so fires do not spread readily across the area.

On the other hand, the controlled burning of large blocks of woodland is much less expensive, although the costs are affected by the same factors previously mentioned. Each prescribed burn of tracts fired so frequently that fuels are scattered is twice as expensive as that of tracts less frequently burned and on which fuels are continuous (Table 3). The lack of good boundaries also greatly increases the cost of control-burning wooded blocks. For example, in 1945 two tracts were control-burned on the same day. One contained 59 acres, the other 90. Neither had been burned for 21 years and fuel accumulations were comparable. Both tracts were bounded by roads or swamps. However, on the 59-acre tract, 19 acres were excluded because of other ownership or the presence of reproduction. Raking the necessary lines and burning the remaining 40 acres required 11 man-hours. The 90-acre tract was burned as a unit in less than 3 man-hours. At \$1 per man-hour, the burn on the first tract cost 27.5 cents per acre, and on the second, 3.3 cents an acre. Over 70 percent of the difference in cost is attributed to the poor boundaries used in burning the smaller tract.

Size and shape of tracts are important factors also because of their effect on the amount of

firing necessary per unit area. For example, two adjoining tracts on the Lebanon State Forest have each had two controlled burns. One area of 22 acres is bound by roads; the other, of 110 acres, by roads and swamps. In each case the perimeter that has to be fired is 1.1 miles long. The costs of the burns have been 27 and 20 cents per acre for the smaller tract, and 3 and 4 cents per acre for the larger area. The differences have been chiefly due to the proportionally greater amount of firing and patrol necessary on the smaller area because of its small size and poor shape.

Burning conditions are also an important factor. When fuels are rather dry and the desired fire intensity can be obtained only by firing against the wind, labor costs may be twice those necessary when firing with the wind gives satisfactory results. The judgment and experience of personnel are likewise important. In control-burning one tract in the winter of 1946-47, an attempt was made to include an area with heavier fuel accumulations than prevailed on the remainder. This mistake quadrupled the man-hours required because of the additional work necessary in suppression and patrol. Personnel should be available for burning work when conditions are suitable. In this respect controlled burning is analogous to the haying job of a farmer. The most satisfactory work, as well as the cheapest, is usually obtained from crews regularly employed on the area, and least from crews hired several days in advance for a specific period.

The costs presented in Table 3 are higher than need be expected on managed areas where controlled burns of tracts are made at 4- to 10-year intervals by experienced personnel. In the first place, the initial burns made after 20 years of fire exclusion are more expensive than subsequent ones. Secondly, the costs shown in Table

TABLE 3.—COST OF CONTROLLED BURNS AS AFFECTED BY TYPE AREA AND PAST TREATMENT¹

Type of area	When control-burned	Total area	Area burned per man-hour	Cost per acre	Range in cost per acre
		Acres	Acres	Dollars	Dollars
Small areas around buildings	Annually for 10 years or more	10	0.74	1.35	1.30-1.40
Safety strips 25-200 feet wide	Annually or biennially, usually for 10 years or more	138	1.1	.94	.70-1.33
Tracts of 23-71 acres	Annually for 6-10 years	262	2.9	.34	.21- .78
Tracts of 52-133 acres	Biennially for 6 years	185	6.6	.15	.12- .17
Tracts of 22-80 acres	For the first time	220	5.2	.19	.14- .27

¹Cost figures are on the basis of \$1 per man-hour. All burns were made in the winter of 1946-47.

3 include line preparation and the additional firing necessary on old safety strips that border some of the tracts. Consequently, the present evidence is that, in the case of tracts having the proper size, shape, and boundaries, a periodic burn can be made at the rate of 10 or more acres per man-hour, or no more than 10 cents an acre.

IDEAL ARRANGEMENT OF AREAS FOR PRACTICAL MANAGEMENT

Studies and experience indicate that the solution to the fire problem in the South Jersey Pine Region might be greatly aided by (1) breaking up large forested areas into units bounded by roads or swamps, and (2) treating a certain proportion of these units by controlled burning. The ideal arrangement would be units in a checkerboard pattern or similar system. In the case of large holdings, units should be about 100 acres in size as these are more economically treated than smaller ones. Protection and silvicultural needs would be coordinated in the burning treatments. Stands having an average diameter less than 3 inches would thus alternate with ones having larger trees. The latter units would be control-burned at appropriate intervals. Fire would be excluded from the younger stands until the trees had reached the size when controlled burning could be safely undertaken.

The protection of such an ideal area from a severe, wild fire would be relatively simple, for there would be a 50-50 chance that it would strike one of the control-burned units. There the fire either would die out or could be easily suppressed. If it should strike one of the unburned units, it would be bounded on all sides by control-burned areas so that probably only the one unit would suffer. While a fire might pass from one unburned unit to another on the diagonal, the chances for holding it at the relatively small points of contact would be good.

APPLICATION OF CONTROLLED BURNS IN PRACTICAL MANAGEMENT

Hindrances.—The forest areas of the Pine Region do not, of course, have an ideal arrangement at the present time. The road system is inadequate for such a pattern, and occasionally there are unbroken units as large as 5,000 acres.

Property lines seldom coincide with the roads. Tracts that are bounded by roads and swamps are often irregular in shape. Moreover, within many units there is much intermixing of both

types and age classes. Many of the upland stands and a still higher proportion of the pine swamps are composed largely of stems whose size renders them susceptible to damage from even light fires (2).

Immediate program.—The problem of introducing controlled burning on a larger scale in the Pine Region obviously presents many difficulties. The conditions for a control-burning program are far from ideal. However, careful surveys will usually show that patterns resembling the ideal arrangement can be developed, although the initial use of controlled burns may be limited to the preparation of barrier zones. For the immediate future, the following program is suggested:

1. Limit the control-burning program to areas that can be properly supervised.
2. After the preparation of suitable plans, extend the control-burning program to all appropriate state lands.
3. As an aid to fire protection on both state and private lands prepare barrier zones to break up large forest areas. This would prevent the development of large wild fires. These barrier zones would consist of control-burned belts supplementing swamps, or other natural barriers.
4. When private owners of forest land request control-burning either for fire protection or as a dual-purpose tool in the management of their lands, detailed plans based on careful surveys should be made by competent foresters. It may be necessary for the owner to construct roads or plowed fire lines before controlled-burning can be started. The burning should be done by crews especially trained by the state but paid by the private owner.

Plans have been made for the controlled burning of some private holdings, following the procedure described above, and some burns have been made. Each plan includes a map of the holding showing the location of individual tracts and of recommended improvements. One sheet of a standard form is usually sufficient for describing the suggested improvements, but separate sheets of a second standard form are prepared for each tract or block (Fig. 2).

Silvicultural practices.—If controlled burning is to be used successfully in the Pine Region of southern New Jersey, certain silvicultural practices should probably be followed.

Species more susceptible to fire damage than the native hard pines should not be introduced

except on restricted areas for experimental purposes. White and red pines have been planted here, but neither does well in this region (6, 7). Loblolly pine, while relatively resistant to fire injury (1), is still of questionable value in this forest region.

Cutting practice should be directed toward the development and maintenance of even-aged stands occupying units adequately bounded (i.e., by roads and swamps) to permit the most economical use of controlled burns.

Thinning from below is desirable where conditions are appropriate, but should be done only in conjunction with controlled burning. Thinning alone accelerates the invasion by hardwoods and shrubs, and without controlled burning favors undesirable hardwoods over the pine.

Thinning should be made uniformly over a

unit, for otherwise fuels tend to vary in moisture content. Such variation increases the difficulty of obtaining a uniform, light burn over the unit.

Slash from thinnings should be so disposed that it will not constitute a hazard in subsequent controlled burns. This can be done either by piling and burning or lopping and scattering. In either case it should be kept well away from the boles of remaining trees.

On the areas periodically control-burned, seed-bed conditions will be favorable and many pine seedlings will start. These will be killed by shade or the subsequent fire, but new ones will replace them. Thus there should be a nucleus of advance reproduction when the burns are discontinued and harvest cuttings initiated. The amount and distribution of advance reproduction should

S A M P L E

New Jersey Department of Conservation
PRESCRIBED BURNING PLAN - Sheet No. 2

Owner John Doe Date August 1947
Location of area Near Pasadena, Ocean County
Block No. 3 Area of Block 60 acres

1. Forest type: Upland
2. Overwood: Oak-pine, well stocked
Average diameter trees 6" Average height 40'
3. Understory: Medium; blueberry and huckleberry
4. Litter: Medium; oak leaves and pine needles
5. Number of annual burns needed to reduce present fuel accumulation: 2
6. Frequency of burns thereafter: at 4 to 5-year intervals
7. First burn recommended in winter of: 1947-48
8. Estimated degree of danger first burn: Low

FORESTER G. Smith

FIG. 2.—Sample sheet prepared for a 60-acre tract in a 2,000-acre holding.

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determine whether the single seed tree or two-cut shelterwood method is followed in these cuttings.

SUMMARY AND CONCLUSIONS

This paper summarizes the experience and research in using controlled burns in the Pine Region of southeastern New Jersey. The primary object of the use of fire as a tool is to provide protection of large blocks of forest land from the devastating fires that periodically sweep the area. Controlled burning does not eliminate the need for organized fire suppression, but supplements it.

At the same time this type of burning greatly favors reproduction of pines instead of that of the less desirable hardwoods.

The central principle of the recommended practice consists in the interspersal of burned with unburned units to provide favorable patterns of defense against the advance of wild fires. The controlled burning of the selected units should be done at favorable seasons of the year, mostly during the period between Christmas and March 1. On the basis of present data controlled burning at intervals of 4 to 5 years is indicated for upland stands in which the diameter of the average dominant is 3 inches or more.

In this region protection and silviculture are phases of the same problem. Controlled burning

can be used as a dual-purpose tool. On the basis of experience and study extending over 20 years, the authors are convinced that controlled burns are the key to management of upland sites in the Pine Region of southeastern New Jersey.

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Fuel treatments reduce the severity of wildfire effects in dry mixed conifer forest, Washington, USA

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Abstract: To address hazardous fuel accumulations, many fuel treatments are being implemented in dry forests, but there have been few opportunities to evaluate treatment efficacy in wildfires. We documented the effectiveness of thinning and prescribed burning in the 2006 Tripod Complex fires. Recent fuel treatments burned in the wildfires and offered an opportunity to evaluate if two treatments (thin only and thin and prescribed burn) mitigated fire severity. Fire severity was markedly different between the two treatments. Over 57% of trees survived in thin and prescribed burn (thinRx) units versus 19% in thin only (thin) and 14% in control units. Considering only large-diameter trees (>20 cm diameter at breast height), 73% survived in thinRx units versus 36% and 29% in thin and control units, respectively. Logistic regression modeling demonstrates significant reductions in the log-odds probability of tree death under both treatments with a much greater reduction in thinRx units. Other severity measures, including percent crown scorch and burn severity index, are significantly lower in thinRx units than in thin and control units. This study provides strong quantitative evidence that thinning alone does not reduce wildfire severity but that thinning followed by prescribed burning is effective at mitigating wildfire severity in dry western forests.

Résumé : Pour s'attaquer au danger que représente l'accumulation des combustibles, plusieurs traitements des combustibles ont été appliqués dans les forêts sèches, mais il y a eu peu d'occasions d'évaluer l'efficacité de ces traitements lors d'incendies de forêt. Nous avons documenté l'efficacité de l'éclaircie et du brûlage dirigé dans le cas des incendies du Tripod Complex de 2006. Les aires où les combustibles avaient été traités récemment ont brûlé lors de ces incendies, ce qui a fourni l'occasion d'évaluer si deux traitements (une éclaircie seule ou combinée à un brûlage dirigé) ont diminué la sévérité du feu. La sévérité du feu a été très différente selon le traitement. Plus de 57 % des arbres ont survécu dans les aires traitées par une éclaircie suivie d'un brûlage dirigé (ECLBRUL) comparativement à 19 % dans les aires qui avaient seulement été éclaircies (ECL) et 14 % dans les aires témoins. En ne considérant que les arbres de gros diamètre (>20 cm de diamètre à hauteur de poitrine), 73 % des arbres ont survécu dans les aires ECLBRUL comparativement à respectivement 36 % et 29 % dans les aires ECL et témoins. Un modèle de régression logistique a mis en évidence une réduction significative de la probabilité de mortalité des arbres dans le cas des deux traitements, mais la réduction était beaucoup plus forte dans les aires ECLBRUL. D'autres mesures de sévérité du feu, dont le pourcentage de roussissement des cimes et l'indice de sévérité du feu, avaient des valeurs significativement plus faibles dans les aires ECLBRUL que dans les aires ECL et témoins. Cette étude démontre clairement de façon quantitative que l'éclaircie appliquée seule ne réduit pas la sévérité des incendies de forêt, mais qu'une éclaircie suivie d'un brûlage dirigé est une mesure efficace pour diminuer la sévérité d'un incendie de forêt dans les forêts sèches de l'Ouest américain.

[Traduit par la Rédaction]

Introduction

With a legacy of fire suppression and exclusion, millions of hectares of dry forests in western North America have fuel accumulations that are considerably higher than prior to the 20th century (Covington 2003; Hessburg et al. 2005). Wildfire frequency and area burned have increased over the past 50 years, and this trend is expected to continue under global warming scenarios (Gillett et al. 2004; McKenzie et al. 2004; Westerling et al. 2006). A variety of fuel treatments are being applied to dry forests throughout the interior

West (see Agee and Skinner 2005 and Peterson et al. 2005 for reviews). Because regular prescribed burning generally reduces surface fuels, it is one of the more promising approaches to fire hazard reduction (Agee and Skinner 2005; Finney et al. 2005; Johnson et al. 2007). However, prescribed burn windows generally are short due to potential smoke impacts and fire hazard (Riebau and Fox 2001; Stephens and Ruth 2005). In most western forests, the area treated with fire remains low compared with the millions of hectares that might benefit from treatment (Stephens and Ruth 2005). Surrogate treatments involving forest thinning

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and biomass removal are being implemented in many dry forests (Graham et al. 1999; Peterson et al. 2005).

A central principle underlying most fuel reduction programs is that they will mitigate the occurrence of high-severity fire events in areas with historic high-frequency, low- and mixed-severity fire regimes (Agee and Skinner 2005). Although many fuel treatment programs are being implemented, there have been few opportunities to quantitatively evaluate treatment efficacy in wildfires. Existing studies generally agree that mechanical thinning followed by prescribed burning is the most effective at mitigating wildfire severity (Finney et al. 2005; Ritchie et al. 2007). The effectiveness of fuel reduction programs, particularly that of prescribed burning, is also supported by fire behavior and effects modeling (Stephens and Moghaddas 2005; Johnson et al. 2007). Better representation of forest types and climatic regimes is needed to assist managers in planning and prioritizing fuel treatments. More definitive evidence and guidelines on the relative effectiveness of different types of fuel treatments are also needed to provide the scientific basis for fuel treatment planning in the West.

We conducted an opportunistic study to determine the relative success of recent fuel treatments in mitigating wildland fire severity, as represented by tree mortality and damage (i.e., bole char and crown scorch). The 2006 Tripod complex fires burned over 70000 ha of mixed conifer forests and involved numerous fuel treatments, including units that had been thinned and prescribed burned within 10 years prior to the wildfire event. Our main objective was to evaluate differences in wildfire severity in stands with thin treatments (thin), thin and prescribed burning treatments (thinRx), and no treatment (control) within the Tripod Complex fires.

Methods

Study area

Treatment units are located within the southwestern section of the Tripod Complex fires approximately 10 km north of Winthrop, Washington (Fig. 1). The study area is located in the Methow Valley Ranger District of the Okanogan-Wenatchee National Forest. Climate is characterized by cold winters and warm dry summers with a prolonged summer drought. Mean annual temperature is 15.1 °C, ranging from -11.6 °C (January annual average minimum) to 30.1 °C (July annual average maximum) (Western Regional Climate Center, Winthrop, Washington, www.wrcc.dri.edu). Mean annual precipitation is 3600 mm with 70% of precipitation falling between October and March, predominantly as snow. Topography is highly dissected with steep slopes and numerous subdrainages (Barksdale 1975). Soils are generally coarse-textured Andisols with high gravel content (Natural Resources Conservation Service 2008).

Study units are located in low- to midelevation forests (Table 1). These forests are primarily composed of multi-aged stands of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), ponderosa pine (*Pinus ponderosa* P.&C. Lawson), and lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.). Western larch (*Larix occidentalis* Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) are occa-

sional stand associates. Understory plant assemblages are sparse in these dry forests. Common shrubs include antelope bitterbrush (*Purshia tridentata* (Pursh) DC) and snowbrush (*Ceanothus velutinus* Dougl. ex Hook.). Common herbaceous species include beardless bluebunch wheatgrass (*Agropyron spicatum* var. *inerme* (Scribn. & J.G. Sm.) Heller), pinegrass (*Calamagrostis rubescens* Buckl.), Idaho fescue (*Festuca idahoensis* Elmer), and raceme pussytoes (*Antennaria racemosa* Hook.) (Ohlson 1996).

Fires were historically common, with an estimated 2- to 18-year fire return interval between 1700 and 1900 from fire scar records at low elevations (Ohlson 1996). Over the past 50-100 years, fire intervals have lengthened due to fire exclusion, and forest assemblages have shifted from ponderosa pine dominance to higher densities of Douglas-fir (Lehmkuhl et al. 1993). Prior to the Tripod Complex fires, wildfires had not occurred throughout much of the study area in over 80 years.

The 2006 Tripod Complex fire was one of the largest fire events for Washington State in the past 50 years. It was preceded by hot dry weather and an ongoing mountain pine beetle (*Dendroctonus ponderosae* Hopkins, 1902) outbreak in mid- to high-elevation lodgepole pine forests. The fires initiated as two lightning strikes and converged under extreme fire weather conditions, spreading as a mixture of crown fires and variable-intensity surface fires. The fires initiated on 3 July and 23 July and were finally extinguished in early November from snow and rainfall events. Over 60% of the area burned was classified as moderate to high severity (US Forest Service 2008).

Sampling design and treatment description

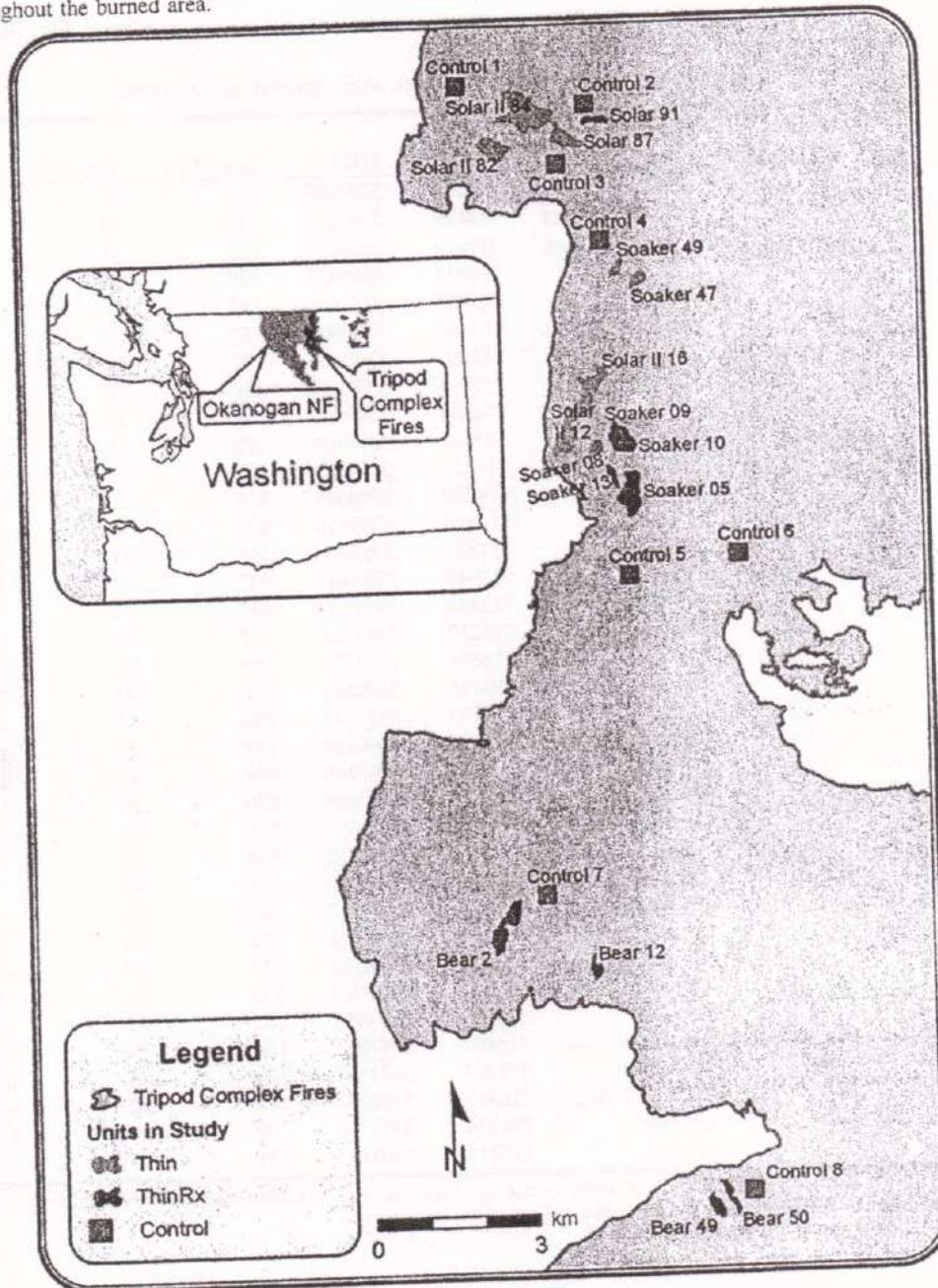
Of the treatment units available for this study, several were excluded because they were located along the wildfire perimeter or were surrounded by unburned forest. We also limited treatment units to those that had been harvested or prescribed burned within the past 15 years. Units adjacent to known burnout operations were also excluded from the study, but with increasing distance from where burnouts initiated, it was unclear whether units burned as a result of the wildfire or fires ignited in burnout operations. For a balanced study design, sample size was constrained by the availability of thinRx units that met selection requirements. Eight thinned units and eight thinRx units were selected for this study (Table 1).

Eight control units with no record of harvesting or burning were randomly selected within the matrix of treatment units. Control unit selection was buffered 0.4 km from the Tripod perimeter and within 0.8 km of road access. A standard area of 8 ha was delineated for each control unit. A 2006 Burned Area Reflectance Classification image (Forest Service Remote Sensing Applications Center) was used to confirm that selected controls were not surrounded by unburned forest and were burned by the wildfire.

Mechanical thinning prescriptions included both thin-from-below harvests that targeted small-diameter and understory trees and shelterwood harvests that removed both understory and overstory trees. All timber harvests were completed 8-15 years prior to the wildfire event and were mostly whole-tree harvested by tractor. The four Solar II thin units were helicopter logged, and tree crowns were left

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Fig. 1. Study area. Thin, recently thinned units; thinRx, recently thinned followed by prescribed burn units; control, unmanaged areas randomly selected throughout the burned area.



on site (Table 1). Recent (2006) burn plans are available for all Solar II units and estimated fuel loads include 9-13 $\text{Mg}\cdot\text{ha}^{-1}$ of fine fuels (<7.6 cm diameter), 9-22.4 $\text{Mg}\cdot\text{ha}^{-1}$ of large woody fuels (>7.6 cm diameter), 0.7-2 $\text{Mg}\cdot\text{ha}^{-1}$ of litter, and 9-13 $\text{Mg}\cdot\text{ha}^{-1}$ of duff. Burn plans (2005) also are available for three of the tractor-logged thin units (excluding Soaker 8) and include the following estimated fuel loads: 11-24 $\text{Mg}\cdot\text{ha}^{-1}$ of fine woody fuels, 22-54 $\text{Mg}\cdot\text{ha}^{-1}$ of large woody fuels, 5-7 $\text{Mg}\cdot\text{ha}^{-1}$ of litter, and 6-11 $\text{Mg}\cdot\text{ha}^{-1}$ of duff.

Prescribed burns were conducted on thinRx units between 0 and 6 years prior to the wildfire event. Hand lines were

constructed around each unit, and units were hand- or helicopter-ignited. Burning took place either in the spring or in the fall, and all burns were recorded as successful, with full coverage and accomplishing fuel reduction objectives of reducing fine fuels by 90%-100% and large fuels by up to 70%.

An additional paired sampling design was used to evaluate differences in fire severity between treated units and adjacent untreated control stands that had similar topography and likely experienced similar fire weather at the time of the wildfire. Adjacent areas were excluded if they were upslope of the treated unit, across a major road or perennial

Table 1. Treatment unit names, area, estimated burn date(s), coordinates, aspect, slope gradient, and elevation.

Treatment	Unit(s)	Area (ha)	Estimated burn date(s)	UTM_E	UTM_N	Aspect (°)	Slope (%)	Elevation (m)
Control	C1	8.2	20 Aug.	712257	5397643	260	44	855
	C2	8.2	15 and 16 Aug.	714629	5397311	313	52	1409
	C3	8.2	18 and 19 Aug.	714114	5396203	323	45	1303
	C4	8.2	10 Aug.	714915	5394812	228	30	1731
	C5	8.2	20 Aug.	715484	5388596	157	31	1150
	C6	8.2	17 and 18 Aug.	717466	5389005	53	54	1266
	C7	8.2	10 Aug.	713983	5382667	97	21	1422
	C8	8.2	29 and 31 July	717795	5377142	236	36	1499
Thin	Soaker 8	4.9	16 Aug.	714860	5390967	177	46	1437
	Soaker 47	11.4	10 Aug.	715619	5394106	228	36	1747
	Soaker 49	3.3	10 Aug.	715227	5394285	162	27	1787
	Solar 87	12.2	18 Aug.	714260	5396683	210	31	1362
	Solar II 12	28.5	16 Aug.	714420	5391410	222	44	1399
	Solar II 16	11.0	14 Aug.	714821	5392234	257	31	1603
	Solar II 82	14.7	18 and 19 Aug.	712940	5396481	237	28	1165
	Solar II 84	41.9	16 and 17 Aug.	713540	5397157	237	23	1294
ThinRx	Bear 2	22.4	20 Aug.	713227	5382066	117	30	1430
	Bear 12	5.7	18 and 19 Aug.	714898	5381307	86	21	1495
	Bear 49	7.3	10 Aug.	717113	5376841	329	52	1450
	Bear 50	6.5	1 and 10 Aug.	717370	5377041	286	47	1437
	Soaker 5	8.1	16 Aug.	715509	5390125	134	27	1390
	Soaker 9 and 10	19.1	15 and 16 Aug.	715330	5391140	107	18	1432
	Soaker 13	4.5	16 Aug.	715175	5390460	226	26	1346
	Solar 91	5.3	16 Aug.	714816	5397017	211	26	1523
C_thin	Soaker 8 C	—	16 Aug.	714900	5390712	178	46	1394
	Soaker 47 C	—	10 Aug.	715546	5394260	219	33	1754
	Soaker 49 C	—	10 Aug.	715205	5394210	162	22	1768
	Solar 87 C	—	18 and 19 Aug.	714088	5396708	179	33	1313
	Solar II 82 C	—	18 and 19 Aug.	712844	5396575	239	35	1098
	Solar II 84 C	—	16 and 17 Aug.	713451	5431010	237	33	1247
	Bear 2 C	—	20 Aug.	713468	5381954	81	42	1377
	Bear 12 C	—	19 and 20 Aug.	714807	5381261	154	19	1501
C_thinRx	Bear 49 C	—	10 Aug.	717435	5377162	332	45	1428
	Bear 50 C	—	31 July, 1 Aug.	716919	5376747	296	52	1484
	Soaker 9 and 10 C	—	15 Aug.	715534	5391189	80	35	1385
	Soaker 13 C	—	16 Aug.	715115	5390397	234	46	1308

Note: Sampling area was not determined for adjacent controls. Control, control unit; Thin, thin units; ThinRx, thinned followed by prescribed burn units; C_thin, adjacent control to thin units; C_ThinRx, adjacent control to thin and prescribed burn units.

stream from the treatment, and (or) had distinctly different topography (i.e., >30% slope gradient and (or) >90° difference in aspect). Not all thin and thinRx units had suitable adjacent controls. A total of six thin and six thinRx units were paired with adjacent controls (Table 1).

Due to the geographic span of treatment units, sample plots burned over a range of days in late July and August. Approximate burn dates were estimated from a fire progression map and are listed in Table 1. Fire behavior between 29 July and 1 August was recorded as low with some localized fire spread and crown fire activity. Predicted maximum temperatures were 17-27 °C and minimum relative humidities were 20%-50% with midflame windspeeds of 3-6 km·h⁻¹. Fire activity increased substantially on 10 August with extreme fire behavior noted in many areas. Predicted maximum temperatures were 18-23 °C and minimum relative humidity was 45%-55% with strong winds between 16 and

24 km·h⁻¹ with gusts up to 40 km·h⁻¹. Most of our study units burned between 15 and 20 August, and extreme fire behavior was noted during this period, including active crowning and rapid fire spread. Predicted maximum temperatures were 21-29 °C and minimum relative humidity was 14%-27%. Predicted midflame windspeeds were between 14 and 27 km·h⁻¹. Fire danger ratings reached a 10-year high between 17 and 20 August.

Field sampling methods

Units were sampled with circular plots along systematic grids. We used a nested plot sampling design to accommodate variable tree densities. Treated units (e.g., thin and thinRx) were sampled using 0.2 ha plots. Control units were sampled using 0.08 ha plots to account for generally much higher tree densities in all size classes. In stands with tree densities <30 trees per plot irrespective of size class, an

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trees were tallied within the largest radius plot. In denser stands, smaller tree size classes were sampled in subplots: trees between 10 and 20 cm diameter at breast height (DBH) were sampled in 25.4 m radius subplots and trees <10 cm DBH were sampled in 5.1 m radius subplots. Trees with heights <1.4 m were not sampled. A minimum of 10% of each unit was surveyed.

Plots were marked with a permanent center stake and numbered metal tag. At each plot, we collected general plot information including site description, aspect, slope gradient, slope position (i.e., lower slope, midslope, upper slope, ridgetop), and site severity for the entire plot (US Department of the Interior National Park Service 2003). The following measurements were collected for each sampled tree: DBH (centimetres), crown base height (metres), height to live crown (metres), tree height (metres), maximum height of crown scorch (metres), minimum and maximum bole char (metres), percentage of the crown volume that was scorched, and tree severity index (US Department of the Interior National Park Service 2003). Tree burn severity classes were defined as follows: 1 = unburned, 2 = scorched foliage, 3 = lightly burned (some foliage and small twigs burned), 4 = moderately burned (foliage and small stems consumed), and 5 = severely burned (only charred stems remain). Recent downed trees that fell after the wildfire (e.g., logs with uncharred wood at severed stems) were tallied as trees. For consistency in observations, field personnel regularly compared and calibrated estimates of percent crown scorch, site severity index, and tree severity index.

Live trees were tagged at tree bases facing plot center for sampling of tree status in subsequent years. During the summers of 2008 and 2009, plots that had live trees in 2007 were revisited to record subsequent tree mortality. Plots with 100% mortality were marked in the center but were not revisited in subsequent years.

Data analysis

Individual stand variables and fire severity measures were summarized by unit (Table 2). To test for differences in tree mortality following wildfire between thin, thinRx, and controls, we conducted a one-factor ANOVA on measures of tree fire severity for thin units, thinRx units, and controls (Sail et al. 2007). Where ANOVA indicated statistical differences between treatments (including treatments and adjacent controls), pairwise comparisons were made using Tukey honestly significant differences tests. In cases where data were not normally distributed, equivalent nonparametric tests were used.

Because tree mortality data are binary (i.e., either live or dead), we used binomial generalized linear modeling to evaluate effectiveness of treatments on tree mortality (R programming language). A logistic model was constructed to predict the proportion of dead trees by treatment type ($p < 0.05$).

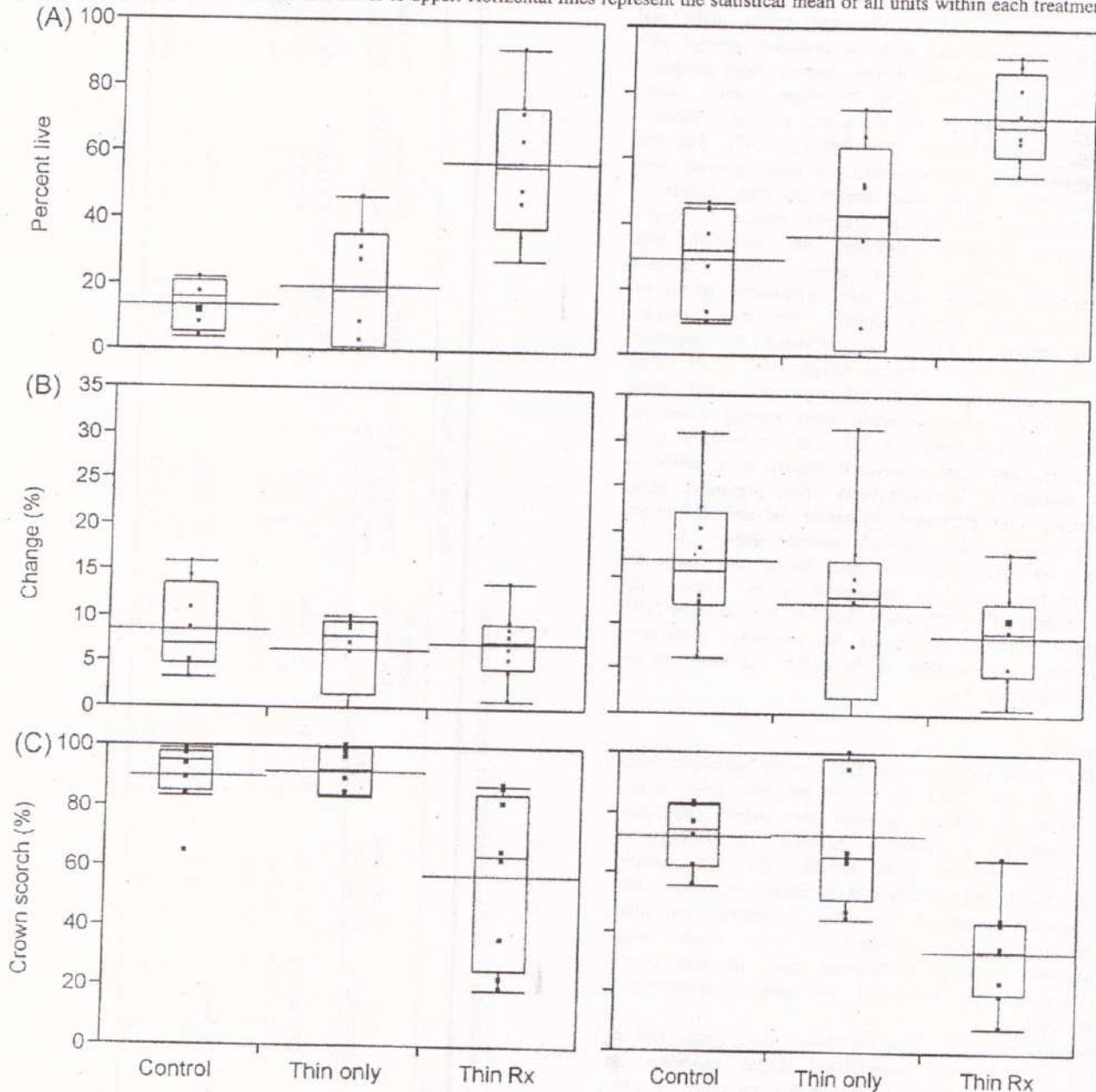
With greater crown heights and thicker bark, large-diameter trees have a better likelihood of survival than small trees (Agee 1993). Small trees were more numerous in thin and control units than in thinRx units. To remove this potential bias, we performed an additional set of analyses on trees >20 cm DBH.

Table 2. Mean and SD (in parentheses) of stand variables and fire severity measures.

	Stand variables			Fire severity measures					Burn severity index (1-5)	
	Diameter (cm)	Density (trees·ha ⁻¹)	Crown base height (m)	Height (m)	Height to live crown (m)	Crown scorch maximum height (m)	Minimum bole char (m)	Maximum bole char (m)		% crown scorch
All trees										
Control	11.8 (2.7)a	1403 (463)a	3.2 (1.1)	9.0 (1.8)	8.8 (2.4)a	8.4 (1.5)	2.2 (1.5)	3.7 (1.6)	90.1 (11.6)a	2.7 (0.3)a
Thin	16.7 (7.1)a	475 (360)b	3.3 (0.9)	10.6 (3.1)	8.1 (2.4)a	9.8 (3.2)	2.5 (2.1)	5.3 (3.2)	91.8 (7.4)a	2.8 (0.2)a
ThinRx	22.1 (8.3)b	172 (131)b	3.3 (1.5)	12.4 (4.0)	5.9 (1.3)b	7.3 (1.6)	0.9 (1.1)	2.4 (1.2)	57.3 (28.0)b	2.3 (0.5)b
Large-diameter trees (>20 cm DBH)										
Control	35.1 (5.9)	166 (58a)	6.0 (1.5)	20.1 (2.3)	10.3 (1.8)a	17.3 (2.2)a	4.7 (2.9)a	8.0 (2.3)a	72.3 (10.9)a	2.4 (0.3)a
Thin	38.0 (4.4)	78 (18)b	5.4 (0.9)	18.6 (1.4)	7.4 (4.7)b	16.0 (2.5)a	4.1 (3.6)a	7.9 (3.9)a	72.6 (22.7)a	2.5 (0.4)a
ThinRx	37.3 (3.1)	53 (30)b	5.4 (2.5)	19.5 (2.0)	7.4 (1.7)b	11.2 (3.2)b	0.7 (0.3)b	3.2 (1.1)b	34.0 (17.5)b	1.9 (0.3)b

Note: Significant differences ($p < 0.05$, bold text) between control units, thin units, and thinned and prescribed burn units are indicated by different letters.

Fig. 2. (a) Percent live trees by treatment for all trees and large-diameter trees (>20 cm DBH), (b) percent change in mortality 1 and 2 years postfire, and (c) percent crown scorch by treatment for all trees and large-diameter trees. Box plots represent minimum, 25% quantile, median, 75% quantile, and maximum values from lower to upper. Horizontal lines represent the statistical mean of all units within each treatment.



Results

Stand characteristics vary by treatment type (Table 2). As expected, tree density is significantly lower in thinRx and thin units than in control units. Thin units tend to be denser than thinRx units, but this difference is not significant. Tree diameter is significantly higher in thinRx units than in thin and control units. There are no significant differences in tree height or height to crown base between treatments.

Most fire severity measures in thinRx units significantly differ from those in thin and control units. As of 2009, over 57% of all trees survived in thinRx units versus 19% in thin

and 14% in control units (Fig. 2). Other tree severity measures, including percent crown scorch and burn severity index, are significantly lower in thinRx units than in thin and control units (Table 2). Mean percent crown scorch is over 90% in thin and control units compared with 57% in thinRx units. In contrast, there are no significant differences in fire severity measures between thin and control units.

Differences in tree severity are more evident when only large-diameter trees (>20 cm DBH) are considered. Over 73% of large-diameter trees survived in thinRx units versus 36% in thin and 29% in control units (Fig. 2). All measures of large-diameter tree severity in thinRx units are signifi-

Table 4. Mean percentage of live trees and SE and binary generalized linear regression models of tree mortality in 2009.

Treatment	Mean % live (SE)	Equation coefficient (SE)
Standard control, all trees		
Null variance reduction 30%		
Control (β_0)	13.91 (2.63)	1.8283 (0.0125)
Thin (β_1)	19.43 (6.52)	-0.5002 (0.0222)
ThinRx (β_2)	57.39 (7.70)	-1.7037 (0.0303)
Standard control, large trees		
Null variance reduction 41%		
Control (β_0)	29.24 (5.70)	0.9382 (0.0278)
Thin (β_1)	36.47 (10.68)	-0.6664 (0.0476)
ThinRx (β_2)	73.11 (4.69)	-1.8721 (0.0593)
Adjacent thin control, all trees		
Null variance reduction 3%		
Adjacent control (β_0)	17.08 (7.85)	1.6229 (0.0169)
Thin (β_1)	25.90 (6.76)	-0.4251 (0.0252)
Adjacent thin control, large trees		
Null variance reduction 13%		
Adjacent control (β_0)	27.63 (11.80)	0.9494 (0.0343)
Thin (β_1)	48.63 (9.73)	-0.9514 (0.0535)
Adjacent thinRx control, all trees		
Null variance reduction 20%		
Adjacent control (β_0)	29.44 (6.50)	1.2810 (0.0173)
ThinRx (β_2)	63.13 (9.10)	-1.4534 (0.0407)
Adjacent thinRx control, large trees		
Null variance reduction 56%		
Adjacent control (β_0)	40.02 (6.95)	0.5754 (0.0365)
ThinRx (β_2)	77.34 (5.01)	-1.7349 (0.0731)

Note: Regression models reflect the change in log odds of mortality relative to control units. The equation form is $\log\text{-odds}(\text{mortality}) = \log[p/(1-p)] = \beta_0 + \beta_1 X_{11} + \beta_2 X_{12}$, where p is the probability of mortality, β is each equation coefficient, $X_{11} = 0$ for control and thinRx units and 1 for thin units, and $X_{12} = 0$ for control and thin units and 1 for thinRx units. The equation intercept is the log odds of mortality for control units. Negative coefficient values indicate a reduction in log odds of mortality in treated units relative to the control. All equation coefficients are significant at $p < 0.05$.

Dispersed logging slash combined with extreme fire weather likely contributed to intense surface fire behavior and high tree mortality in thin units. Piled and burning of logging slash might have mitigated wildfire severity (Strom and Fule 2007) but was not conducted on any thin units. Because this was an opportunistic study, we have limited information about prefire surface fuel conditions. In all thin units, logging slash was characterized by forest managers as light using fuel model 11 with $<12 \text{ Mg}\cdot\text{ha}^{-1}$ of fine woody fuels $<20.3 \text{ cm}$ in diameter (Anderson 1982). Litter accumulations were low, with depths $<2 \text{ cm}$. Prefire shrub cover was not recorded, but shrub cover is low in these dry forests and probably did not contribute substantially to surface fire behavior. Prefire surface fuel data are not available on thinRx units, but prescribed burns were reported as successful in all units, with a reduction of $>90\%$ of fine surface fuels. Treatment of fine, downed woody debris and litter accumulations likely reduced surface fire intensity, flame lengths, and convective and radiative heating in thinRx units and contributed to lower postfire severity measures as compared with thin and control units.

Although tree density is not significantly different between thin and thinRx units, thin units generally have higher tree densities associated with a higher proportion of small-diameter trees and saplings than thinRx units. When considering only large-diameter trees, overall tree mortality is still much higher in thin than in thinRx units and is not significantly different from that in control units. Differences in fire severity measures between treatments (i.e., maximum height of crown scorch, minimum/maximum bole char, percent crown scorch, and tree burn severity index) were all higher in our analysis of large-diameter trees. In both thin and thinRx units, large-diameter trees are almost exclusively Douglas-fir, ponderosa pine, and western larch, all species that are resistant to fire at larger diameters and therefore have a better chance of survival (Agee 1993). Two thin units (Solar II 82 and 84) are exceptions, with mortality comparable with that in thinRx units. Both units were helicopter-logged and recorded fine woody fuel accumulations similar to those in other thinned units. Adjacent controls sustained high tree mortality, indicating that the units had severe wildfire around them. However, large-diameter ponderosa pines

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cantly different from those in thin and control units (Table 2). Maximum bole char is over 7.9 m in thin and control units versus 3.2 m in thinRx units. Percent crown scorch is 72% in thin and control units versus 34% in thinRx units. Considering only large trees, there still are no significant differences in fire severity measures between thin and control units.

The paired analysis of treated units versus adjacent controls resulted in similar findings (Table 3). Compared with adjacent controls, tree diameter is significantly higher in thinRx units. Tree density is significantly lower in both thin and thinRx units compared with adjacent controls. Considering all tree diameters, tree mortality and other measures of fire severity (i.e., minimum/maximum bole char, percent crown scorch, and burn severity) are significantly lower in thinRx units than in adjacent controls. There are no significant differences in fire severity measures between thin units and adjacent controls. When only large-diameter (>20 cm DBH) trees are considered, results are again very similar. Mean height and diameter of large trees are significantly higher in both thin and thinRx units than in adjacent controls. Although differences in fire severity measures are highly significant between thinRx and adjacent controls, there are no significant differences between thin units and adjacent controls.

Logistic regression models reveal significant reductions of the log-odds probability of tree death under both thin and thinRx treatments (Table 4). Both thin and thinRx treatments reduced the log-odds probably of tree mortality relative to adjacent controls, but thinRx treatments had much greater reductions than thin treatments (Table 4). Results are similar when only large-diameter trees are considered.

Tree mortality was surveyed for 3 years following the wildfire event. Following the initial survey in 2007, an additional 18% of trees died in 2008 and 7% of trees subsequently died in 2009. Percent change in tree mortality between 2007 and 2009 does not significantly differ by treatment (Fig. 2). Tree mortality markedly differs by species (Fig. 3) with the lowest mortality for western larch (21%) and ponderosa pine (39%) and highest mortality for lodgepole pine (91%) and Engelmann spruce (88%). Overall mortality for Douglas-fir is 66%.

Discussion

This study provides strong quantitative evidence that without treatment of surface fuels, thinning does not reduce tree mortality during a large wildfire. With lower tree densities and fewer understory trees than unmanaged controls, thin units likely were effective at reducing crown fire potential but not tree mortality. We did not observe evidence of crown fire in thin stands; in the first 2 years following the wildfire, red needles were retained on most dead trees (Fig. 4). In contrast, control units comprise a mixture of scorched patches of trees and areas where needle and branchwood in tree crowns were consumed by fire. High tree mortality in thin units likely was associated with cambial heating and crown scorch from intense surface fires. Maximum bole char and crown scorch height both were highest in thin units, suggesting long flame lengths and particularly high-intensity surface fires in those units.

Table 3. Mean differences and SE of the mean difference (in parentheses) between adjacent controls and treated units.

	Stand variables				Fire severity measures					
	Diameter (cm)	Density (trees-ha ⁻¹)	Crown base height (m)	Height (m)	Height to live crown (m)	Crown scorch maximum height (m)	Minimum bole char (m)	Maximum bole char (m)	% crown scorch	Burn severity index (1-5)
All trees										
Thin vs. control	4.496 (3.291)	-430 (191)	-0.031 (0.709)	2.024 (1.457)	0.917 (2.318)	1.776 (1.618)	-1.968 (2.051)	0.175 (2.078)	0.658 (6.126)	-0.142 (0.189)
ThinRx vs. control	8.755 (4.877)	-774 (208)	0.688 (1.111)	3.996 (2.419)	-2.083 (1.167)	-1.696 (1.779)	-1.975 (0.579)	-2.004 (0.746)	-37.610 (12.241)	-0.462 (0.194)
Large-diameter trees (>20 cm DBH)										
Thin vs. control	5.166 (2.050)	-71.7 (12.8)	0.295 (0.685)	0.894 (0.724)	1.044 (2.692)	0.454 (1.468)	-4.092 (3.092)	-2.524 (2.844)	-6.170 (12.505)	-0.205 (0.225)
ThinRx vs. control	6.028 (1.844)	-115.6 (29.0)	0.9296 (1.2858)	2.814 (1.199)	-1.4228 (0.9590)	-4.5809 (1.9237)	-4.1761 (1.5250)	-4.2645 (1.4823)	-42.610 (7.785)	-0.5233 (0.1294)

Note: Positive differences indicate that treated values are greater than controls. Significant differences ($p < 0.05$) are indicated by bold text.

Fig. 3. Percent live trees by major tree species in 2007, 2008, and 2009.

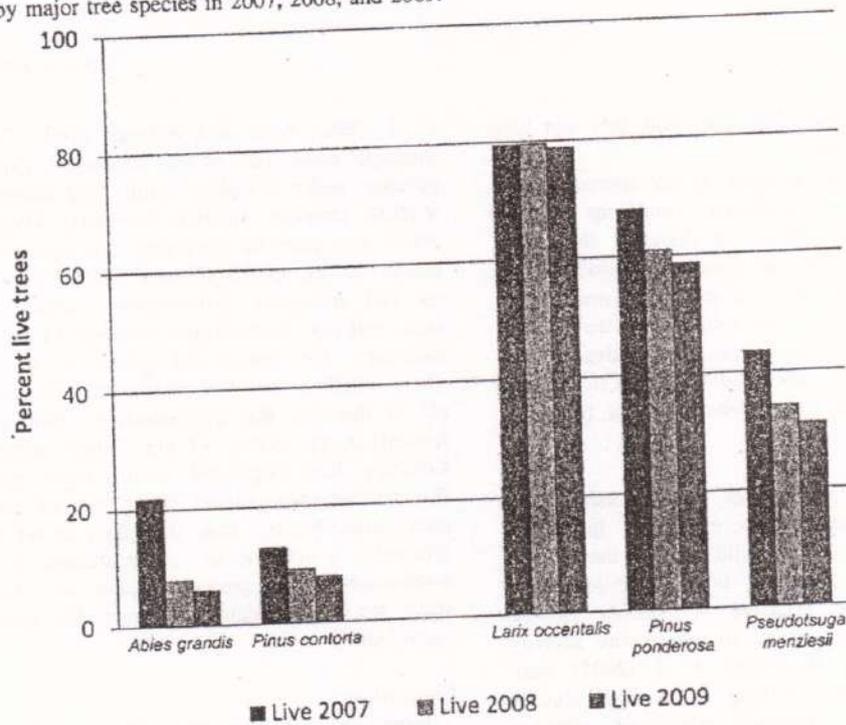
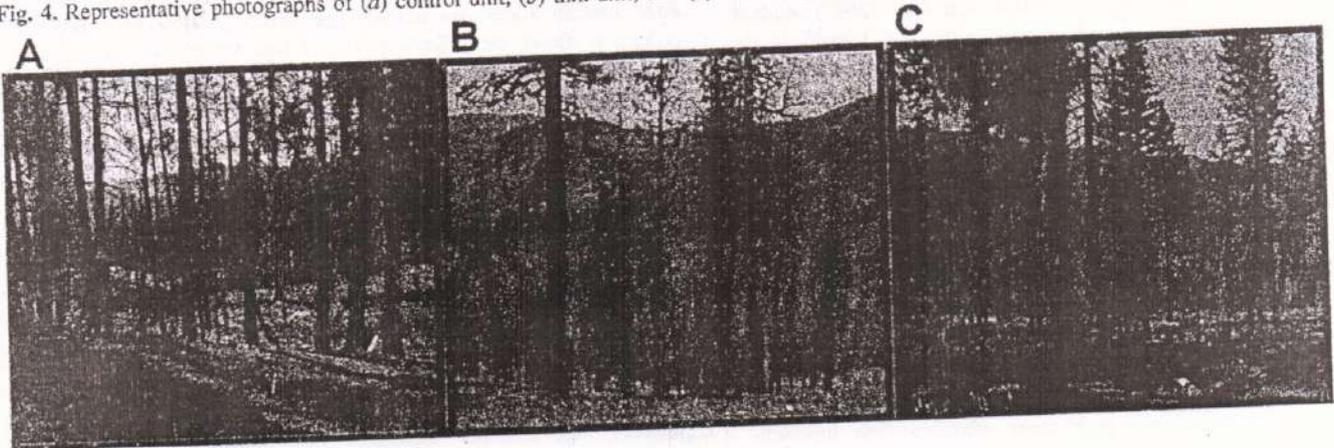


Fig. 4. Representative photographs of (a) control unit, (b) thin unit, and (c) thin and prescribed burn unit.



were common in both stands and may have contributed to lower mortality on these units. Our results strongly suggest that thinning alone does not mitigate wildfire severity, even when considering large-diameter trees.

When all tree sizes are considered, two thinRx units (Soaker 5 and Bear 50) have relatively high mortality. Both units were mechanically thinned, but clusters of small-diameter trees were retained. Mortality of these small-diameter trees may have been associated with the prescribed burn of the units and preceded the wildfire event.

Unit size does not appear to be a factor in treatment effectiveness. Even small thinRx units (4-5 ha in size) had low fire severity, indicating that size may not be as important as treatment type in predicting fire severity. Our results suggest that small units with low tree density and low surface fuels can alter fire behavior and reduce fire severity

within a larger matrix of high-intensity wildfire (Agee et al. 2000). Small units may not affect landscape fire spread (Finney et al. 2005) but could provide protection buffers of local resources such as structures, municipal water sources, and rare species habitat (Johnson 2008).

Location-specific records of burnout operations are not available for the Tripod Complex fires. However, based on known ignition points, it is likely that some thin and thinRx units (specifically Soaker 5, 8, and 13 and Solar II 12) were impacted by burnout operations rather than the actual wildfire. At lower elevations, burnouts tended to be of higher intensity than the actual wildfire (Rick Lind, Tonasket Ranger Station, personal communication). The two thinRx units (Soaker 5 and 13) effectively mitigated fire severity, whereas the two thin units (Soaker 8 and Solar II 12) had high mortality. However, it is possible that fire severity

may have been lower in these thin units had they not been involved in burnout operations.

Wildfires can be extremely variable in fire spread and intensity due to changeable environmental conditions such as fire weather and topography. When we designed this study, we added an additional analysis of adjacent controls to test for differences between treatments in areas that presumably experienced similar fire weather and behavior as the wildfire burned into the control and treated units. Our analysis of adjacent controls demonstrated very similar results to those of our balanced ANOVA design and corroborates our findings.

Management implications

Results from this study closely agree with published field research and fire behavior and effects modeling. In a field-based, retrospective study of five wildfires in the interior West, Omi et al. (2006) found that thinning followed by slash treatment was the most effective at reducing fire severity, whereas thin treatments failed to reduce fire severity and in some cases increased it. Finney et al. (2005) evaluated the efficacy of prescribed burning in the 2002 Rodeo-Chediski fire in Arizona and reported significant relationships between the age, size, and frequency of past prescribed burns and lower fire severity. Strom and Fule (2007) studied thinned stands where slash had been piled and burned in the Rodeo-Chediski fire and found significant reductions in fire severity compared with untreated stands. Safford et al. (2009) also reported significant differences in tree mortality in thinned units where slash had been piled and burned relative to untreated areas in the Angora fire, California. In a study of fire severity following a wildfire in northern California, Ritchie et al. (2007) reported the highest tree survivorship in units that were thinned and prescribed burned. The effectiveness of fuel reduction programs, prescribed burning in particular, is also supported by fire behavior and effects modeling (Raymond and Peterson 2005; Stephens and Moghaddas 2005; Johnson et al. 2007). The national Fire and Fire Surrogates study also demonstrated that prescribed burns treatments were more effective than mechanical treatments at reducing surface fuels (Schwilk et al. 2009).

Given the similar findings to other studies, our results should be applicable to many dry forests with low- to mixed-severity fire regimes in the western United States. However, they may *not* apply to forests with flammable shrub and (or) grassland understories. Both thinning and prescribed burning can increase shrub dominance by creating gaps in the forest canopy (Bailey and Tappeiner 1998). For forest types in which flammable understory shrubs could be released by fuel treatments, the efficacy and longevity of treatments could be reduced compared with the dry forests of our study area. For example, in a landscape analysis of fire severity in the 2002 Biscuit fire in southwestern Oregon, Thompson and Spies (2009) reported that shrub cover was one of the most important predictors of fire severity. Plantations and other clearings involved in the Biscuit fire experienced the highest incidence of fire severity and were associated with a flammable shrub stratum.

Although individual fuel treatments may be effective at reducing fire severity, they may do little to alter fire spread across landscapes unless they are strategically placed (Agee

et al. 2000; Agee and Skinner 2005; Finney et al. 2005). Strategic placement of fuel treatments can be difficult to implement under complex terrain and management units (e.g., wildlife reserves, riparian corridors) (Peterson and Johnson 2007) but may be necessary to suppress and or alter the course of fire spread (Finney 2007). Our study concentrated on fuel treatment effectiveness within specific treatment units and not on landscape patterns of fire spread. However, landscape fire spread did appear to be influenced by previous wildfires and fuel treatments. The most striking example of this was the approximately 1000 ha 1974 Forks fire located in the center of the Tripod perimeter. The Tripod Complex fires originated to the south and north of the old fire and wrapped around either side of the young lodgepole pine forest, burning only the edges of the regenerating trees. Similarly, a network of fuel treatments is located along the southwestern fire perimeter and was used as defensible space for back-burning to prevent fire spread toward nearby communities.

Conclusions

From fire behavior and effects modeling and available field-based studies, it appears that fuel treatments that reduce surface fuels *can* reduce fire severity. However, little is known about the effectiveness of fuel treatments in steep terrain and under extreme fire weather (Peterson et al. 2005). Although fuel treatments in this study appear to have had an impact even under extreme fire weather and steep terrain, weather and topography may supersede the importance of fuel treatments in other situations (Bessie and Johnson 1995; Cary et al. 2009). Validation of the effects of silvicultural and fuels management techniques for additional wildfires using real-time fire weather and behavior records would increase confidence in using these treatments more broadly to reduce fire hazard in fire-prone landscapes.

Increasing evidence shows that mechanical thinning followed by surface fuel removal is the most effective management approach to mitigate wildfire severity in dry forests. However, fire and fuel managers face numerous challenges in developing strategies for fuel reduction treatments. Prescribed fire is less expensive than mechanical or manual fuel removal but is often difficult to implement due to smoke management concerns and narrow windows of safe burning conditions. Targeting critical areas such as wildland-urban interfaces and appropriate forest types (e.g., those that historically supported high-frequency, low-intensity fire regimes) may help optimize resources (Agee et al. 2000; Agee and Skinner 2005; Peterson et al. 2007). Strategic placement of these fuel treatments may also be effective at limiting fire spread across critical landscapes (Finney 2007).

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**WORKING PLAN
OF
DEHRADUN FOREST DIVISION
SHIWALIK CIRCLE
VOLUME - I
PART-II
(FUTURE MANAGEMENT)
PERIOD
(2020-21 TO 2029-30)**



Revised under the supervision of
Sanjeev Chaturvedi, I.F.S.

C.C.F. Working Plan,
Uttarakhand

Compiled & Submitted by
P.K. Patro , I.F.S.
C.F/ Working Plan Officer



- iv. Use of modern technologies such as use of Drone and satellite-based alert system are very useful for timely detection of forest fire.
- v. Provision of enough communication and transport system.
- vi. Public participation by making them aware that it is their moral & legal responsibility to report & to help in controlling fire.
- vii. Making all the telephone numbers (of forest officials) public to facilitate people to report.

19.22.2.2 Control Measures:

- i. Counter-firing and beating the fire with trained firefighting crew.
- ii. Adequate number of firefighting crew at crew stations to be ready to control fire on 24-hour basis.
- iii. Provision of transportation (Jeep/Tractor with trolley & water tankers) for each range for fast response & to minimize damage.
- iv. Adequate hand tools for firefighting to be made available at crew stations.
- v. Modern equipment like Leaf blower, pressurized water sprinkler, fire extinguishing balls etc. are very useful

19.22.2.3 Firefighting methods: The different methods of fire fighting in the forest are as follows:

- i. **Extinguishing with water:** Small forest fire can be extinguished by throwing water on it. But there is limitation to this method in the sense that water may not be available in the areas. On the other hand, fire does not occur in areas near water source or moist areas.
- ii. **Extinguishing with soil (earth):** Soil or earth can be used for extinguishing forest fire because it is always available at sites. The soil can be dug out and thrown to the fire to put out. If fire occurs in hard and rocky areas it is not feasible to use this method. Most of the areas of the division are of such nature.
- iii. **Extinguishing with beating:** Surface fires are generally controlled by beating them out. For this purpose, 'jhapa' are made of branches of the nearby shrubs and small trees. Then, men standing on the periphery of the fire beat it out. This is the best way to extinguish creeping, ground and surface fires.
- iv. **Extinguishing with counter-fire:** Crown fire and infernos are controlled by counter-fire. People move ahead of the fire and start burning the areas in the opposite direction after clearing line. In such case, the two fires from the opposite direction meet somewhere and got extinguished. This is usually the best method to fight big fire and the safest.

19.22.2.4 Mopping up: This is very important for the success of firefighting works done on the ground. In places where smoke is coming out from burnt debris; burning material should be opened so that unburnt fuel can also burn. Mopping up should be done in such a way that the fire does not spread to adjoining areas. Following precautions are necessary in mopping up operation:

- i. Smouldering blocks, bushes and trees should be checked properly and any trace of fire should be extinguished with soil or water before leaving the area.
- ii. Sufficient manpower should be employed for extinguishing the remaining fire. The tools like Pulaski and others should be used for this purpose.

- iii. The big heaps of ash should be spread to find out any fire that maybe present in it and the same should be extinguished.

19.22.2.5 Hand tools: The following hand tools are of great utility during control of forest fire effectively:

- i. Double edge axe: This is utilized for cutting shrubs, branches of trees.
- ii. Brush hook: This is utilized for cutting shrubs, and branches of trees.
- iii. Pulaski: This is used for removing roots of trees and shrubs and also utilized for cutting shrubs.
- iv. Macloid: It is used for making and cleaning fire lines and for throwing Soil.
- v. Shovel: This is used for throwing earth and can also be used for cutting branches up to 2 cm diameter.
- vi. Rake: This is used for clearing leaves twigs etc.
- vii. Naif Sake pump: This is used for mopping up works.

19.22.2.6 Other Control Measures: Effective fire management requires three steps, i.e. prevention, detection & control. Following are some of other important activities: -

- i. Preparation of annual fire plan
- ii. preparation of annual fire risk map.
- iii. Creation of Public awareness.
- iv. Annual assessment of infrastructure and equipment.

19.23 Fire reporting & assessment of damage: This is also an important aspect of fire management & for preparation of future strategy. The check list is as follows:

- i. Number of fire incidents, mapping and measuring the area.
- ii. Investigation- causes, lapses in fire prevention and reporting, responsibility of personnel.
- iii. Assessment of fire damage.
- iv. Fire effects on top canopy, middle, lower and ground vegetation & forest floor
- v. Fire effects on ground & soil conditions.
- vi. Injuries to trees and effects on growth due to damage to leaves, stems & barks.
- vii. Damage to young seedlings and regeneration.
- viii. Effect on micro-climate and vegetation tending towards xerophytic succession.
- ix. Damage to animals, birds, Insects and micro-organisms.
- x. Effect on ecology and environment.

19.23.1 Assessment of the Loss Caused by Fire: Fire causes both tangible and intangible damages to the forests and wild life. Loss of regeneration, timber, NTFP and wildlife are tangible while loss of soil fertility, soil constituent and wild life habitat etc. are intangible. Fire damages lead to increase in rate of soil erosion and causes drying up of water sources. Fire causes adverse effect on regeneration and destroys under growth leading to invasion by weeds. Natural succession goes into retrogression. Wild animals and birds are killed.

19.23.2 The valuation of loss caused by forest fire is generally calculated on the basis of direction issued vide Chief W.P letter no. 638/27-2, dated, 22.1.2020. Detail is given below: -

गढ़वाल 694 वन प्रभाग

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(गढ़वाल वृत्त, उत्तराखण्ड)

की

प्रबन्ध योजना

(अवधि नियंत्रण वर्ष 2024-25 से 2033-34)

संजीव चतुर्वेदी, भा०व०से०
मुख्य वन संरक्षक, कार्य योजना
उत्तराखण्ड, हल्द्वानी के निर्देशन में

एन०एन०पाण्डेय, भा०व०से०

वन संरक्षक, गढ़वाल वृत्त

पंकज कुमार, भा०व०से०

कार्य योजना अधिकारी द्वारा संकलित

खण्ड-1 (भाग-1)



उत्तराखण्ड शासन

मुख्य वन संरक्षक, कार्य योजना
उत्तराखण्ड, हल्द्वानी

फायर लाईनों का रख-रखाव :- प्रभाग के आरक्षित वनों में पूर्व में आवश्यकतानुसार विभिन्न लम्बाई व चौड़ाई की अग्नि रक्षा पट्टियों का निर्माण किया गया था, जिनका मुख्य उद्देश्य संवेदनशील वन खण्डों में वनाग्नि के प्रसार को रोकने व प्रभावित स्थल पर शीघ्रता से पहुंचने तथा आवश्यक सामग्री व संसाधन पहुंचाना था। वर्तमान में इन फायर लाईन्स में लम्बे समय से रख-रखाव न होने के कारण विभिन्न प्रकार के वन उगकर स्थापित हो गये हैं। वर्तमान में फायर लाईनों पर उगे हरे वृक्षों के पातन पर प्रतिबन्ध हट जाने के कारण इनका नियमित रख-रखाव किया जाना अतिआवश्यक है। क्षेत्र भ्रमण में चिन्हित फायर लाईनों में से कुछ का निरीक्षण किया गया तथा यह पाया गया कि वर्तमान में चिन्हित स्थलों पर फायर लाईन होने का प्रमाण नहीं है। यह हो सकता है कि इनकी स्थिति अन्यत्र हो अथवा वर्तमान में ये वन स्वरूप में परिवर्तित हो गई हों। वर्तमान में प्रभाग के इन फायर लाईनों की कुल लम्बाई लगभग 140 किमी० के 10 गुनी लम्बाई में पक्की सड़कों का निर्माण हो चुका है, जिनसे फायर लाईन के उद्देश्यों की पूर्ति हो रही है। इनके उपयोग से नियंत्रक दल वाहन से शीघ्र घटना स्थल पर पहुंचता है तथा अन्य दुर्घटना नियंत्रक कार्य करता है। ये सड़कें वनाग्नि को रोकने के लिए भी प्रभावी हैं। इनका निर्माण भी आबादी बाहुल्य क्षेत्रों में हुआ है जिनमें अधिकांश चीड़ वन हैं तथा अग्नि अन्य दुर्घटना के लिए संवेदनशील है। वर्तमान में फायर लाईन में उगे वनों को काटकर पुनः सभी फायर लाईन का रख-रखाव किया जाना सार्थक प्रतीत नहीं होता है। जिन अग्नि दुर्घटना के लिए संवेदनशील क्षेत्रों में मोटर मार्गों का निर्माण नहीं हुआ है, वहाँ कम घनत्व के वनों में न्यूनतम वृक्ष पातन को ध्यान में रखते हुए पुरानी फायर लाईनों की सफाई अथवा नई फायर लाईनों के निर्माण के सम्बन्ध में प्रभागीय वनाधिकारी द्वारा निर्णय लिया जायेगा।

21.13.2 अन्य अग्निरोधी पट्टिकाएँ :- उपरोक्त के अतिरिक्त प्रभाग में बड़े पैमाने पर अश्व मार्ग, पैदल मार्ग, लीसा बटिया भी हैं जिनमें आवागमन के सुधार हेतु विशेष रूप से चीड़, पिरुल गिरने के उपरान्त सफाई करने से अग्नि दुर्घटनाओं में कमी पाई गयी है। 05 वर्ष से कम अवधि के रोपण क्षेत्रों में एक फायर वाकर तथा अधिक के रोपण क्षेत्र के चारों तरफ 10 फीट की अग्नि रक्षा पट्टी बनाये जाने से भी अग्नि दुर्घटनाओं में कमी देखी गई है। सड़क, अश्व मार्ग, पैदल बटिया, लीसा बटिया, रोपण बटिया का विस्तृत विवरण वार्षिक वन अग्नि नियंत्रण योजना में दिया जाता है, के अनुसार प्राप्त धनराशि से प्राथमिकता पर कार्य कराये जायेंगे।

21.13.3 नियन्त्रित दाहन :- वन विभाग द्वारा वनाग्नि के कारक जलौनी पिरुल व अन्य पदार्थ को कम करने के उद्देश्य से नियंत्रित दाहन किया जाता है। यह कार्य वनाग्नि काल प्रारम्भ होने से पहले किया जाता है तथा पहाड़ी क्षेत्रों में ऊपर से नीचे लगाया जाता है। नियंत्रित दाहन कठोर अग्नि रक्षित क्षेत्रों में 15 दिसम्बर से 15 फरवरी के मध्य नियन्त्रित दाहन किया जायेगा। वार्षिक नियन्त्रण दाहन के क्षेत्रों का विवरण सारणी-21.9 में दिया गया है। चीड़ वनों में सबसे अधिक आग वर्तमान वर्ष में गिरते पिरुल के कारण होता है, जो अप्रैल से जून के बीच गिरता है। अतः वनाग्नि काल से पूर्व लगाए जा रहे आग से पुराने गिरे पिरुल नष्ट होता है। पिरुल की मात्रा कम करने हेतु इनको जलाने के अतिरिक्त इनका उपयोग वन क्षेत्रों में चैकडेम बनाने या अन्य उपयोगों यथा जैविक खाद, ब्रिकेट्स, बिजली उत्पादन, पेपर इत्यादि हेतु वन क्षेत्रों से बाहर निकाले जाने के उपाय किये जाने चाहिए।

वार्षिक नियंत्रण दाहन के क्षेत्र

द्विवार्षिक नियंत्रित दाहन वाले क्षेत्र

नियन्त्रित दाहन की प्रक्रिया :- नियन्त्रित दाहन करते समय निम्नलिखित नियमों/निर्देशों का पालन किया जाएगा:-

- (1) सामान्यतः नियंत्रित दाहन 15 फरवरी तक पूर्ण हो जाना चाहिए। दाहन का समय मौसम की शुष्कता, अभिमुख, ऊंचाई तथा वनों में विद्यमान ज्वलनशील पदार्थों की मात्रा के ऊपर निर्भर करता है। नियंत्रित दाहन करते समय न्यूनतम सम्भावित क्षति के उद्देश्यों को सर्वोपरि रखना चाहिए। ऐसा न करने पर अग्नि के नीचे से ऊपर तेजी से फैलने की प्रवृत्ति के कारण सस्य को क्षति पहुंच सकती है।
- (2) दाहन का कार्य सदैव सूर्यास्त के पश्चात् अथवा रात्रि में किया जाना चाहिए।
- (3) लीसा टिपान वाले क्षेत्रों में नियंत्रित दाहन से पूर्व वृक्षों के चारों ओर भली-भांति सफाई (जड़ सफाई) कर देना चाहिए। अग्नि दाहन से पहले चीड़ वन क्षेत्रों से लीसा टिन, गमले आदि अवश्य हटा लेने चाहिए।
- (4) हक-हकूक, लघु मांग छपान के अवशेष प्रकाष्ठ मलबे को नियंत्रित फुकान से पूर्व हटाया जाना चाहिए।
- (5) वनों से जाने वाली मोटर मार्गों के दोनों ओर 5 मीटर तक सफाई कर ज्वलनशील पदार्थ जला देना चाहिए।
- (6) आरक्षित वनों में नियंत्रित दाहन करने से पूर्व इसकी सूचना समीपवर्ती सिविल सोयम, पंचायती वनों से सम्बन्धित पटवारियों, ग्रामवासियों, सरपंचों को अवश्य दी जानी चाहिए। इनकी संकलित सूची रेन्ज स्तर से क्षेत्र समिति प्रमुख तथा वन पंचायत अधिकारी को भी उपलब्ध करा दी जानी चाहिए।
- (7) तरुण सस्य क्षेत्रों में अग्नि दाहन का कार्य वनकर्मियों के दल के देख-रेख में कराया जाना चाहिए।

21.13.4 कठोर अग्नि रक्षा वाले क्षेत्र :- इसमें चीड़ के युवा सस्य वाले क्षेत्र (पुनरुत्पादन की ऊंचाई 1.5 मीटर से कम), पुनरुत्पादन के अन्तर्गत चीड़ के क्षेत्र, अपुनरुत्पादित चीड़ क्षेत्र, समस्त चौड़ी पत्तियों वाली प्रजातियों के क्षेत्र, बांज कार्यवृत्त, फर, स्प्रूस, देवदार कार्यवृत्त के क्षेत्र तथा प्रबन्धापीन क्षेत्र के वे समी वृक्षारोपण क्षेत्र जिनमें पौध छोटी है, सम्मिलित हैं (सारणी-21.11)। कठोर अग्नि रक्षित क्षेत्रों का विवरण प्रतिवर्ष के सिल्वीकल्चर प्लान ऑफ ऑपरेशन में दिया जाए तथा समस्त क्षेत्र को कठोर अग्नि सुरक्षा प्रदान करने हेतु निम्न कार्यवाही की जाए।

1. अग्नि रक्षित क्षेत्रों को बीट मानचित्रों में दर्शाया जाए। नये क्षेत्र इस श्रेणी में आने पर उनको भी मानचित्र में अंकित किया जाए।
2. प्रति वर्ष ग्रीष्म काल से पूर्व (सामान्यतया जनवरी) में अग्नि रक्षित क्षेत्रों की सूची राजि अधिकारी, अनुभाग अधिकारी, लीसा चौकीदार तथा बीट वन रक्षकों को भेजी जानी चाहिए, जिसमें उनसे सम्बन्धित कठोर अग्नि रक्षित तथा नियंत्रित फुकान वाले क्षेत्रों की सूची दी जानी चाहिए तथा जो कार्यवाही उनसे अपेक्षित है, उसका विवरण दिया जाना चाहिए।
3. इन क्षेत्रों के लिये पृथक से अग्नि रक्षकों की नियुक्ति की जानी चाहिए।
4. इन क्षेत्रों के चारों ओर विद्यमान अग्नि रक्षा पट्टियों की नियमित रूप से वार्षिक सफाई तथा फुकान किया जाना चाहिए। अग्नि रक्षा पट्टी न होने पर इन क्षेत्रों के चारों ओर 30 मीटर चौड़ी पट्टी का नियमित रूप से वार्षिक फुकान किया जाना चाहिए, जिससे यह अस्थाई अग्नि रक्षा पट्टी का कार्य कर सके।
5. अग्नि रक्षित क्षेत्रों के समीप के क्षेत्रों में नियंत्रित फुकान किया जाना चाहिए।

6. अग्नि रक्षित क्षेत्रों से गुजरने वाले मार्ग तथा बटियाओं को और उनके दोनों ओर 10 मीटर दूरी तक के क्षेत्रों को साफ रखा जाए। उनमें ज्वलनशील पदार्थ (पिरूल, सूखी पत्तियां आदि) एकत्र न होने दिये जायें।
7. अग्नि रक्षित क्षेत्रों में विभागीय कर्मचारियों की देख-रेख में अग्नि काल से पूर्व घास कटवा दी जाए।
8. कक्षों/उपकक्षों के चीड़ युक्त क्षेत्रों में ही नियंत्रित फुकान किया जायेगा। ढंगरी क्षेत्रों में तथा रिक्तियों में कदापि आग नहीं जाने दी जायेगी।
9. कक्षों/उपकक्षों में स्थित रोपण क्षेत्रों को कठोर रूप से अग्नि से बचाया जायेगा।

सारणी-21.11

कठोर अग्नि संरक्षित क्षेत्रों की सूची

कार्यवृत्त	अभ्युक्ति
चीड़ कार्यवृत्त	इसमें चीड़ के युवा सस्य वाले क्षेत्र (पुनरुत्पादन की ऊँचाई 1.5 मी० से कम), पुनरुत्पादन के अन्तर्गत चीड़ के क्षेत्र, अपुनरुत्पादित चीड़ के क्षेत्र सम्मिलित हैं।
बाँज कार्यवृत्त	सम्पूर्ण कार्यवृत्त की कठोर अग्नि सुरक्षा आवश्यक है।
फर, स्पूस, देवदार कार्यवृत्त	सम्पूर्ण कार्यवृत्त की कठोर अग्नि सुरक्षा आवश्यक है।

21.13.5 चीड़ के वनों से पिरूल/टीटें हटाना :- चीड़ वन वनाग्नि हेतु अत्यधिक संवेदनशील होती है। यद्यपि यह वृक्ष वनाग्नि सहनशील है, बार बार हो रही वनाग्नि तथा कम व्यासवर्ग के वृक्ष में आग लगने से तथा लीसा घावों में आग लगने से भारी मात्रा में नुकसान होती है। इसके अतिरिक्त मृदा व जल स्तर पर भी दुष्प्रभाव होता है। अतः चीड़ वनों में वनाग्नि का प्रभावी नियंत्रण आवश्यक है। इसके लिए सर्वप्रथम चीड़ वनों से पिरूल की मात्रा घटाना होगा। इसके लिए पिरूल का एकत्रीकरण कर अन्य उपयोगों हेतु प्रयुक्त किया जाना चाहिए। वर्तमान में कतिपय वन प्रभाग द्वारा स्थानीय संस्था की मदद से पिरूल से लट्टे बनाने की दिशा में महत्वपूर्ण पहल किया गया है। गढवाल वन प्रभाग द्वारा भी इस तरह का पहल स्थानीय संस्थाओं की मदद से किया जा सकता है। पिरूल एकत्र करने में ग्रामीणों की मदद ली जाती है तथा कुछ धनराशि उन्हें प्रति कुन्तल के हिसाब से भुगतान किया जाता है। पिरूल का बुरादा बनाने में बुड़ चीटर मशीन की सहायता ली जाती है, तत्पश्चात् गोबर इत्यादि मिलाकर लट्टे बनाये जाते हैं। इस तरह की योजना बनाने से पूर्व ऐसे लट्टों की बिक्री हेतु प्रदेश के अन्दर अथवा बाहर बाजार चिन्हित अवश्य कर लिया जाना चाहिए, जिससे ऐसी योजना दीर्घ कालीन अवधि तक बिना किसी अवरोध के चलता रहे। पायलेट स्तर पर अति संवेदनशील क्षेत्रों का चयन कर पिरूल हटाने की कार्यवाही की जायेगी। पिरूल का उसी वन क्षेत्र में चैकडेम बनाने हेतु भी प्रयुक्त किया जा सकता है, जिसकी तकनीक जल संसाधन प्रबन्ध एवं भूमि संरक्षण (अतिच्छादी) कार्यवृत्त में दिया गया है। इसके अतिरिक्त कम्पोस्ट बनाने, कोयले के टिबिकियां बनाने, बिजली उत्पादन तथा घरेलू उपयोग हेतु पिरूल का निस्तारण किया जा सकता है। चीड़ वनों में व्यापक रूप में उनके टीटें जमीन पर गिरे होते हैं जो वनाग्नि के फैलाव का मुख्य कारण है। आग लगे टीट लुढ़कते हुए व उछलते हुए नालों को भी पार करते हुए अन्य वन क्षेत्रों में भी गिर सकते हैं, जिससे वहां भी वनाग्नि प्रारम्भ होती है। अतः वनाग्नि काल से पूर्व इन टीटों का भी निस्तारण किया जाना चाहिए तथा इसे ईंधन या अन्य प्रयोगों में इस्तेमाल किया जा सकता है। प्रख्यात शोध संस्थान यथा सी०एस०आई०आर० से पिरूल के उपयोग के सम्बन्ध में शोध करवाया जाना चाहिए। वनों से पिरूल निस्तारण को बढ़ावा देने के सम्बन्ध में शासनादेश संख्या-1872 X-2-2016-21(09)/2015, देहरादून दिनांक 06 अक्टूबर, 2016 (परिशिष्ट-18.1) से पिरूल अभिवहन को उत्तराखण्ड इमारती लकड़ी और अन्य वन उपज का अभिवहन नियमावली, 2012 के अन्तर्गत छूट प्रदान की गई है। प्रभाग को उत्तराखण्ड सरकार की पिरूल (चीड़ की पत्तियां) तथा अन्य प्रकार के बायोमास से विद्युत उत्पादन हेतु नीति-2018 के अन्तर्गत इच्छुक उद्यमियों से सम्पर्क हेतु कार्यक्रम आयोजित करते हुए अतिसंवेदनशील वन क्षेत्रों से स्थाई रूप से पिरूल निष्कासन करने के सम्बन्ध में प्रयास किया जाना आवश्यक है इससे वन क्षेत्रों से न केवल फ्यूल लोड कम होगा अपितु निकटवर्ती ग्रामीणों को प्रभाग में वनाग्नि नियंत्रण हेतु पिरूल एकत्रीकरण कार्यों से सीधे जोड़ा जा सकेगा तथा ग्रामीणों की आजीविका में वृद्धि भी होगी। उत्तराखण्ड शासन के पत्र सं० 981/X-2-2023-21(9)2015, दिनांक 16-05-2023 द्वारा राज्य में वनाग्नि नियंत्रण हेतु चीड़ पिरूल एकत्रीकरण कार्यों से स्थानीय जनता को सीधे जोड़ने तथा आजीविका में वृद्धि के उद्देश्य के दृष्टिगत पूर्व निर्गत शासनादेश 2198/X-2-2019-21(9)2015, दिनांक 05-11-2020 में निर्धारित धनराशि रू० 2.00 को पुनरीक्षित करते हुए चीड़ पिरूल एकत्रीकरण हेतु 2.00 प्रति किलोग्राम के स्थान पर रू० 3.00 प्रति किलोग्राम की दर से भुगतान किए जाने की स्वीकृति प्रदान की गई है।

NATIONAL ACTION PLAN ON FOREST FIRE

FOREST PROTECTION DIVISION

MINISTRY OF ENVIRONMENT, FORESTS AND CLIMATE CHANGE

GOVERNMENT OF INDIA

NATIONAL ACTION PLAN ON FOREST FIRE

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List of Abbreviations

1. NAPFF: National Action Plan on Forest Fire
2. MoEF&CC: Ministry of Environment, Forest and Climate Change
3. SFD: State Forest Department
4. DFO: Divisional/District Forest Officer
5. FSI: Forest Survey of India, Dehradun
6. ICFRE: Indian Council for Forestry Research and Education, Dehradun
7. NDMA; National Disaster Management Authority
8. SDMA: State Disaster Management Authority
9. DDMA: District Disaster Management Authority
10. NDRF: National Disaster Response Force
11. SDRF: State Disaster Response Force
12. DFE: Directorate of Forest Education, Dehradun
13. CAMPA: Compensatory Afforestation Fund Management and Planning Authority
14. JFMC: Joint Forest Management Committee
15. SOP: Standard Operating Procedure
16. ICT: Information and Communication Technology
17. NTFP: Non-Timber Forest Produce
18. EDC: Eco-development Committee
19. FRA: Forest Rights Act (Scheduled Tribes and other Traditional Forest Dwellers {Recognition of Forest Right Act, 2006}
20. WPO: Working Plan Officer
21. IT Cell: Information Technology Cell
22. SHG: Self Help Group
23. MNREGA: Mahatma Gandhi National Rural Employment Guarantee Act

National Action Plan on Forest Fires

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1. Statement of Purpose

Fires, both accidental and deliberate, have always played a very important role in shaping forests since ancient times. In India most of the forest fires are attributable to anthropogenic reasons. Communities use it to prepare lands for shifting cultivation, clear forest floor for NTFP collection, promote grass growth for grazing. Criminal gangs of poachers use it to force wild animals come out of safe hiding places, while unintentional fires caused by careless throwing of burning matchsticks and escape of cooking fire from temporary shelters for road workers also account for many forest fires. Forest Survey of India has reported that 54.40% of forests in India are exposed to occasional fires, 7.49% to moderately frequent fires and 2.40% to high incidence levels while 35.71% of India's forests have not yet been exposed to fires of any real significance. Major affected areas lie in the North East India and in the forests on the Deccan plateau. Prolonged droughts make forests vulnerable to fires and the changing climate further aggravates their vulnerability. The fragmentation of most of Indian forests, interspersed with habitations of all sizes, results in high human presence in most forested areas which adds to their vulnerability to fires.

The objective of this National Action Plan on Forest Fires, hereinafter referred to by its abbreviations NAPFF, is to minimize forest fires from taking place by informing, enabling and empowering forest fringe communities and may be incentivizing them to work in tandem with the forest departments. This will substantially reduce the vulnerabilities of forests across the diverse forest ecosystems in the Indian subcontinent against fire hazards, enhancing the capabilities of forest and other personnel and institutions in fighting fires, and speed up recovery after a fire event.

2. General Principles

- i. The prescribed actions in this NAPFF are intended to guide and assist the policy makers, administrators, forest officers, frontline staff, forest user agencies, forest fringe communities, visitors to forests, and civil society, for a holistic management of fires in forests.
- ii. Preventing fires from taking place and improving resilience of the forests against fire hazards shall form priority in forest management policies, strategies and programs with well-defined aims of conservation of biodiversity, wildlife and forest wealth.
- iii. The safety of the people, both resident and transient, firefighters, and fire managers shall always be accorded the highest priority during fire events.
- iv. There shall be a clear line of command for assuming the lead role and duties in the event of a forest fire.
- v. Districts shall form the units for Forest Fire Management planning and implementation for ease in coordination with the Disaster Management Authorities at the national, state and district levels.

3. Fire Risk Zonation and mapping

Forest fire risk zonation provides a scientific basis for identifying areas of priority for management interventions, allocating resources to priority areas, and monitoring the effectiveness of measures to reduce or control fire risk. These risk zones shall be reviewed and updated at least once every five years to respond to any changes in the abovementioned factors.

3.1 Risk factors

The following factors, among other locally relevant, may be considered for identifying and quantifying fire risks:

- i. *Fuels*, including forest cover and type as a broad indicator of fuel type. Optionally, states may perform field-based studies to measure fuel load and type;
- ii. *Proximity to infrastructure, property, and other assets*, including roads, habitations and other buildings, agricultural lands, transmission lines, and railways; *Topography*, including slope, aspect, elevation, terrain ruggedness and other characteristics;
- iii. *Social indicators*, including local dependence on forests for livelihoods, poverty, and traditional land use practices;
- iv. *Historic fire occurrence and patterns* may be used to identify areas that are most prone to fires. Fire records prior to 2003 may be geo-referenced and mapped. This historical data can be used to validate the results of analysis.;
- v. *Areas of special ecological or cultural importance*, including protected areas, historic sites, designated heritage sites, temples, pilgrimage routes, etc.; and
- vi. *Special ecological conditions*, for example, bamboo flowering, may be considered and provided weights.

3.2 Use of fire risk zones in forest planning

The results of the forest fire risk zonation shall be translated into concrete management actions under the forest working plans. The Working Plan Officers (DFOs in the case of Plans already in operation) shall identify activities or interventions to mitigate fire risks or reduce impact of the fire hazards in high-risk areas. These may include creation of additional fire lines, watch towers and other infrastructure in vulnerable areas. The same shall be examined speedily by the appropriate authorities for approval and making provisions for financing the approved activities. The Annual Plan of Operations for all forest divisions and circles, and protected areas, shall include the approved activities and interventions mentioned above. The state planning and finance departments shall prioritize resource allocation for forest fire management.

(Action by SFDs) (Monitoring by SFDs
and MoEFCC)

4. Preventing forest fires

Most forest fires are manmade and are linked to socio-economic and livelihood issues of the forest fringe communities. It should, therefore, be possible to greatly reduce the forest fire incidences by making these communities aware of the many tangible and intangible benefits lost to them, both individually and collectively, due to forest fires. Following actions are proposed to be taken in this regard:

4.1 Effective communication strategy for awareness generation

A mass communication strategy with adequate financial provisions for five years shall be framed by each SFD within two months for vigorous publicity and sensitization of the state in general and local communities in particular. It should be specifically targeted at students, farmers, women groups, cattle herders, NTFP collectors, infrastructure related professionals, urban dwellers, tourists and pilgrims, among others. Information on forest fire and its adverse effects should also be included in the school curriculum at several levels. The strategy would identify most effective means for reaching out to different target groups like school campaigns, campaigns on Radio, TV, and social media, mobile campaigns during festival season, organization of music festivals, and setting up information portals, among others.

(Action by SFDs) (Monitoring by SFDs
and MoEFCC)

4.2 Empowering Communities to deliver on their responsibilities

The existing forest laws mandate the forest officials to seek participation of local communities in fire management. Under the FRA the forest areas recognized under community rights are mandated to be sustainably used by the right holding forest dweller community which places on them the responsibility of conservation of these areas. Similar responsibilities rest on the communities practicing shifting cultivation for protection of forests against damage by fires under their respective state laws. Similar expectations are also placed on the JFMCs and Van Panchayats in relation to the forest lands under their jurisdictions. These communities would be better placed to shoulder these responsibilities if they are adequately empowered with delegated authority and funds. The communities could also be incentivized for their cooperation in fire prevention and control measures in the form of money, rewards, social recognition, preference in Government schemes, etc. The SFDs may evolve state specific mechanisms for this purpose in tune with relevant laws and traditional practices.

(Action by SFDs) (Monitoring by SFDs
and MoEFCC)

4.3 Capacity building of communities

The capacity of community organizations in prevention and control of forest fires should be enhanced by periodical training and capacity building programmes. Forest fire alerts information should also be provided to JFMC/EDC/Van Panchayat members and they should also be provided with firefighting equipment including leaf litter

blowers, other tools and protective clothing. The community members should be duly involved during the mock drills on forest fire before fire season. In the Micro plan of the JFMCs, there should be a separate chapter for forest fire management which should contain the details of vulnerable areas, location of natural & man-made water sources, other infrastructure available for fire prevention and management etc.

(Action by SFDs) (Monitoring by SFDs and MoEFCC)

5. Increasing the resilience of forests to fires

Management interventions for increasing resilience to forest fires may be planned according to the vulnerability to forest fires as reflected in the risk zonation maps. Following are some of the measures which could be adopted in this context.

5.1 Moisture and water conservation

As fire hazard is more in drier and deciduous habitats and areas with predominance of grasses, management action would need to aim at moisture retention for longer time after rains and appropriate preventive measures to ensure that minor fire incidences do not escalate into major fire events. A long-term plan for improving the water regime of the forest areas based on opportunities and feasibility will be useful in reducing vulnerability to fires. Several existing programs for eco-rehabilitation and catchment area treatment plans provide scope for this kind of work.

(Action by SFDs)
(Policy support by MoEFCC)

5.2 Forest floor biomass management

When necessary management interventions may be planned aiming at minimizing accumulation of dry fuel material on forest floor in the fire season. The litter and other biomass on the forest floor leading to fire danger could be gainfully utilised for the benefit of the society in identified areas. A framework for biomass management is suggested below and SFDs are encouraged to experiment with appropriate caution.

- a. Collection of forest floor biomass such as fallen pine needles for use in briquets may be encouraged by the waiver of royalty and transit fee for such collections.
- b. Policies for promoting biomass based off-grid micro power plants in remote areas may be put in place. Space heating in high altitude areas could be tried using excess biomass from forest floors vulnerable to fires.
- c. Guidelines may to be framed for sustainable removal of dead bamboo in the

event of mass flowering to reduce risk of fire and also to conserve biodiversity.

- d. Policies for permitting women SHG to use forest floor biomass with appropriate safeguards for micro entrepreneurship may be put in place by the SFDs.

(Action by SFDs)

(Policy support by MoEFCC)

5.3 Weed Management

Invasive weeds such as Lantana need to be controlled as they contribute significantly to the fire danger and pose a threat to native biodiversity. The following actions are recommended:

- i. A baseline study to quantify the extent and spread of invasive weeds may be initiated by SFDs in consultation with scientific institutions such as ICFRE.
- ii. Lantana removal strategies adopted should ensure it does not regrow on treated lands. Removal should be organized as an attractive economic opportunity for the local communities.
- iii. Rehabilitation of treated areas with appropriate species and soil and moisture conservation measures should form part of the weed removal plan.

(Action SFDs and ICFRE)

(Monitoring by MoEFCC)

6. Forest Fire Preparedness

Preparedness in forest fire management leads to effective response to fire disasters resulting in reduced impact and quicker recovery. The following steps may form the basis of preparedness against forest fires:

6.1 Forest fire detection and alert

Satellite based Forest Fire Alerts are already operational across the country led by FSI. The following steps may be taken to improve the efficacy of the FSI fire alert system:

- i. **Digitization of forest boundaries:** In the absence of digitized boundaries in many forests across the country, the FSI screens fire detections using approximations leading to reduced efficacy of the alert system. The states may, therefore, complete the digitization of forest boundaries at the earliest.
- ii. **Promoting greater adoption of the Forest Fire Alert System:** FSI has put in place a robust forest fire alert system. The States shall encourage the involvement of all field functionaries in the same, so that the forest fire alert system can percolate down to beat level in least possible time. This may be institutionalized through a protocol.
- iii. **Improving Ground based Detection:** Even with the advances in new

remote sensing technologies for fire detection, ground-based detection continues to be essential and should be sufficiently resourced. The SFDs shall perform an assessment of the efficacy of the existing network of watchtowers by a review of the level of functionality and operational use of the existing towers. The WPOs (DFOs in the case of divisions where approved working plans are already in existence) may propose new locations for fire watchtowers based on coverage, visibility, ignition sources, and other relevant factors.

- iv. **Strengthening engagement with local communities:** Local communities are often the first to spot fires and alert the forest department. Locally suitable mechanisms should be developed by the SFDs for sourcing reliable and quick information from local communities.
- v. **Dedicated phone line:** A toll-free telephone number for fire detections and other required support needs to be established at state level to obtain information on forest fires from tourists, passersby and local people.
- vi. **Monitoring and Evaluation:** FSI has put in place a system to review all fire alert detections, and their ground verification. This is a critical step and may be monitored by MoEFCC in the month of December every year. SFDs must ensure that feedbacks on fire alerts are sent to FSI for validation.
- vii. **Wireless network:** In most remote forest areas mobile telephony is not well developed and frontline staff are unable to get the information coming on the Forest Fire Alert Alarms. In such cases, forests communication system may be supplemented by a dedicated wireless network.

(Action: SFDs)
(Monitoring by FSI and MoEFCC)

6.2 Digitize the location of critical resources and assets

The IT Cells of the state forest departments shall conduct inventory mapping of critical resources for forest fire prevention and management and make relevant

information available to the forest divisions. Resources and assets to be inventoried may include forest department resources, such as watchtowers, ground crew stations, controls rooms and fire lines as well as non-department resources, such as the locations of fire stations, fire tenderers and National and State Disaster Response Forces, and army and paramilitary camps. They may also include important infrastructure such as roads, railways, and telecommunications networks and natural resources such as water bodies and natural fire breaks that could assist in preparedness and planning for response to forest fires.

(Action by SFDs)
(Monitoring by MoEFCC)

6.3 Forest Fire Lines

SFDs may undertake the mapping and digitizing of the location of existing fire lines and other infrastructure such as roads, transmission lines, and rail lines that may function as fire breaks. A review of the maintenance status, functionality, and adequacy of these fire lines, and an assessment of the need for new fire lines, may be undertaken considering past fire data, forest types, habitations, and other relevant factors. Proposals for new fire lines should be made on a scientific basis considering their potential efficacy in reducing fire risk and their proximity to people, property, and areas of special concern (e.g., protected areas). Plantations should not be raised on existing or proposed fire lines.

6.4 Control Burning

(Action by SFDs)

Control burning may be necessary in some places for preventing spread of fire. The following actions are recommended to improve the consistent performance and effectiveness of control burning wherever necessary:

- i. Prioritization of areas for control burning as part of the fire risk zonation analysis;
- ii. Monitoring of the performance of control burning at the Circle level, and integration of monitoring data into a database maintained by the SFDs;
- iii. Timely release of funds for control burning prior to the onset of the peak fire season and the provision of advance/ad-hoc release as needed;
- iv. Development of state-specific guidelines for control and prescribed burns to be notified and revised as may be necessary.

(Action by SFDs)
(Monitoring by SFDs)

7. Fire Suppression

Immediate response to forest fires after receipt of information is of utmost importance.

The SFDs must develop a culture of emergent response to fire alerts under which all available resources are used to douse the fire. This needs intense training at all levels, strengthening of infrastructure, and coordination with other relevant agencies.

7.1 Training for field staff, firewatchers, and community firefighters

The principal need for forest fire suppression is to have adequate competent, trained, and equipped workforce on the ground, ready to respond and take immediate action. Training should be provided to field officers, seasonal firewatchers, and community volunteers involved in firefighting. All these firefighters should understand basic principles of forest fire management for using the most effective suppression technique at their

disposal and know when retreat is necessary. The type of training provided to firefighters should be tailored according to the landscape, nature of terrain, their level of responsibility and role in the command structure in responding to fires.

- i. A modern and standardized training curriculum should be developed by the SFDs with the guidance of Directorate of Forest Education (DFE) of the MoEFCC. Other agencies involved in fire response, including National Disaster Management Authority (NDMA), NDRF, and the State Disaster Management Authorities may be involved in a consultative role.
- ii. Mock drills should be organized before fire season at various fire prone areas involving all the stakeholders such as District Administration, Police, Fire Department, NDRF, SDRF personnel, community organizations etc. for identification of gaps in the existing mechanism and better preparedness during crisis time.
- iii. Provision of training, equipment, and coordination should extend beyond state-managed forests to community institutions in regions such as the Northeast, where communities are responsible for managing most of the forest estate.

(Action by SFDs and DFE)
(Monitoring by the MoEFCC)

7.2 Equipping the firefighters

- i. The firefighting squad including field staff, seasonal firewatchers, and community firefighters should be provided with adequate firefighting equipment including leaf litter blowers, and protective clothing.
- ii. The SFDs should take the lead in this process of identifying and providing firefighting equipment suitable to local needs in consultation with the Indian Council of Forestry, Research & Education (ICFRE), Dehradun.
- iii. The ICFRE should focus on development of user-friendly fire fighting equipments, tools and protective clothing suitable for various regions of the country.
- iv. There should be sufficient practice sessions for the fire fighting personnel in the use of the fire fighting equipments including leaf litter blowers, and protective clothing so as to enhance their efficiency in actual fire fighting.

(Action: SFDs, ICFRE)
(Monitoring by the MoEFCC)

7.3 Development of adequate infrastructure for fire suppression

- i. An effective communication network should be ensured in all fire prone forest areas using wireless where necessary.
- ii. SFDs should develop, and enforce, a protocol for ensuring prompt access to field vehicles from nearby forest divisions for movement of firefighting personnel to the fire spots at the earliest.
- iii. Advance technologies such as use of drones should be explored in identification of exact location, intensity & direction of fire to facilitate fire extinguishment at the earliest.
- iv. Forest road network should be properly maintained for quick movement of firefighting forces to the fire site.

(Action: SFDs)
(Monitoring by MoEFCC)

7.4 Arrangements for adequate manpower in fire prone areas

- i. The SFDs should fill all vacancies especially at the level of frontline forest officials in the fire prone areas on priority basis.
- ii. Trained manpower may also be mobilized from other agencies such as Police, District Fire services, NDRF, SDRF etc.
- iii. The Communities living near the fire prone areas should also be sensitized and may be incentivized towards fire suppression activities.
- iv. There should be a mechanism for mobilization of forest fire fighting volunteers and providing them with adequate training on an urgent basis. A database of the firefighting volunteers should be maintained at district level.

(Action: SFDs)

8. Post Fire management

8.1 Assessment of loss due to forest fires

- i. FSI may develop a national level database for burnt area assessment on a yearly basis. Standardized protocols and procedures are needed to facilitate the reporting of the area affected and losses due to forest fire which may be developed by the ICFRE in association with FSI and other institutions.
- ii. MoEFCC may assign ICFRE the responsibility of developing and standardizing methodologies for assessing losses due to forest fire including loss of intangibles such as ecosystem services.
- iii. Based on standardized methodologies, the ICFRE may further standardize protocols for estimating area affected and losses due to forest fire and reporting the same at successive levels.

- iv. The ICFRE may assist the DFE in designing and organizing adequate training programs for forest officials at various levels for this purpose.

(Action: SFDs, ICFRE and FSI)
(Monitoring by MoEFCC)

8.2 Proper investigation of the causes

The SFD shall ensure that the causes for every fire incident are properly investigated and adequate measures taken immediately including legal actions where necessary.

8.3 Restoration of fire affected areas

- i. A proper restoration plan should be prepared at once for the fire affected areas with the objective of restoring to its natural profile. Appropriate silviculture practices should be prescribed taking into account the ecological successional dynamics.
- ii. Adequate soil moisture conservation measures may be taken up in the fire affected areas for enhancing the moisture retention capacity of the land.
- iii. Indigenous vegetative barriers may be identified and planted around the fire affected areas.

(Action: SFDs)

9. Coordination with Other Agencies:

Forest fire management is a multifarious activity in which a frictionless interface with a range of institutions and social groups becomes very important for effective functioning. The SFDs are already working in coordination with the FSI for past many years. Forest fires of disastrous proportions already come under the purview of the National Disaster Management Authority (NDMA) and the Disaster Management Authorities at the state and district levels and institutional mechanisms for combating forest fires at disaster scale has already been formalized for incorporation in the National, State, and District level disaster management plans. Institutionalization of close coordination with relevant institutions is thus already a reality but it needs to be strengthened further. For this purpose there are existing procedures developed by the DMAs at all levels and the SFDs may take urgent steps to update, upgrade and integrate their systems with those of the DMAs. In addition the following steps may be taken by the SFDs.

- i. Functioning of the Crisis Management Groups for Forest Fires at all levels may be reviewed to ensure that Standard Operating Procedures (SOPs) are in place related to command and control, compilation of availability of extent and location of resources required in case of occurrence of fires and for monitoring its spread.
- ii. Organizing mock drills is a very efficient way of ensuring preparedness. MoEFCC and NDMA may provide guidance for action at the state level. Joint trainings and

mock exercises with all relevant agencies may be organized to facilitate coordination during a fire event.

- iii. Assistance of Defense agencies located in the vicinity becomes critical in certain situations where quick and concerted action can make a difference. MoEFCC may need to coordinate at the Ministerial level with the the Ministry of Defense to obtain suitable directions for their field formations so that such extension of assistance becomes a routine matter.
- iv. An escalation matrix may be developed at the state level by the SFDs in consultation with the SDMA to decide at what stage of aggravation of fire crisis the help from SDRF and NDRF should be sought.

(Action: MoEFCC, SFDs, NDMA, SDMAs, DDMAAs)
(Monitoring by MoEFCC)

10. Centre of Excellence for Forest Fires

A Centre of Excellence is needed to be established to undertake data collection and analysis, frontline research in all aspects of forest fires, and development of firefighting equipment and tools. For the past two decades the FSI has been providing excellent leadership in forest fires and it would be most appropriate to set up this institute under the control of the FSI with strong linkages with ICFRE and leading universities across the country. Sufficient additional personnel and financial allocations would be required to enable FSI to undertake this task.

(Action by FSI and MoEFCC)

11. Mobilization of Financial resources

Forest fires pose the foremost threat to India's forests and the threat is projected to become more serious with the changing climate. Therefore, emphasis on the adequate protection of existing forest resources from fire hazards should become high priority attracting adequate funding. Specifically,

- i. The SFDs should make sufficient financial resources available at district, range and local level well in advance of fire season with enough imprest money for ensuring that lack of money does not hamper emergent fire management works.
- ii. While budgetary allocations for fire protection must be earmarked it should be possible to make fire protection integral to many other programs of forest protection. Community development works and entry point activities in forest enclosures and fringes could develop fire protection arrangements on the borders of habitations.

- iii. Climate funds under existing global bilateral or multilateral mechanisms for activities leading to adaptation to the changing climate can be a good source for money and must be accessed.
- iv. For promotion of use of Information and Communication Technology (ICT) standing instructions are already in place for mandatory use of a minimum proportion of total sectoral allocation in ICT in the respective sector. This should be made use of for ICT part of the forest fire detection and protection activities.
- v. MNREGA and community development/welfare programs aimed at generating employment through creation of assets with labour intensive activities are a good source of funding for some aspects of forest fire protection and should be made use of.
- vi. Community Forest Rights have been recognized in forests under The Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006. The Act also empowers the right holders to sustainably use the resources under the community forest rights thus recognized. Activities related to sustainable use of community right forests must also include protection of such areas from overuse and destruction by disasters like fire also. For this purpose, Forest Administration needs to come to assist the stakeholder communities in planning and managing the community rights areas on priority. As the areas under community rights are expected to experience regular human presence, vulnerability to fire hazard is high and is needed to be minimized.
- vii. India has technical cooperation arrangements with several countries where technical and financial assistance can be tapped for augmenting forest fire management capabilities. External financial aid should be accessed for investment on infrastructure for this purpose.
- viii. In the large infrastructure projects particularly river valley projects, Environmental Management Plans and Catchment Area Treatment Plans are mandatorily prepared and implemented at the cost of the user agencies. Such activities can be very useful in augmenting moisture retention capacity of the catchments thus minimizing fire hazards.
- ix. Crowd funding is a popular means of financial resource mobilization for any common cause where interested people can contribute. Environmental causes like forest fire protection can garner enormous support from public. Local community organizations working in vicinity of vulnerable forests can thus be encouraged to organize crowd funding for work at community level. This could be particularly effective in and around areas of tourist, cultural or religious significance located near or within forests etc. MoEFCC could explore the possibility of encouraging this as a policy for people's participation in forest fire protection and management.

Action: SFDs, State governments and MoEFCC
