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Review

Air quality policy and fire management responses addressing smoke from wildland fires in the United States and Australia

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Abstract. Wildland fire emissions degrade air quality and visibility, having adverse economic, health and visibility impacts at large spatial scales globally. Air quality regulations can constrain the goals of landscape resilience and management of fire-dependent ecosystems. Here, we review the air quality regulatory framework in the United States, comparing this framework with that of Australia. In the United States, wildland fire management and air quality policies have evolved independently, yet interact to meet diverse public needs. Australian policy development is more recent and decentralised. We find that (1) for maxiumum effectiveness, smoke and fire regulatory frameworks must keep pace with scientific evidence, environmental and social change, and be accompanied by clear regulatory guidance; (2) episodic, non-stationary qualities of fire, and its role in ecosystems, pose specific challenges to regulators and policy-makers; and (3) the complexity of industry-focused air quality policies often leads to unintended consequences for fire management. More research is needed to create and implement more effective fire and air policies and better prepare social-ecological systems to address the challenges of climate change mitigation. These insights may be helpful for countries initially developing complementary fire and air policies, especially as the role of fire becomes more important geopolitically and globally.

Additional keywords: emissions, regulatory, smoke management.

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Introduction

Wildland fires have been a key component of global social-ecological systems for millennia and a large number of terrestrial ecosystems require periodic burning to maintain them (Agee 1993; Hardy and Arno 1996; Leenhouts 1998; Allen *et al.* 2002). Wildland fires are generally unplanned ignitions that can be actively suppressed and opportunistically managed for resource benefit, or prescribed (planned) fires that are used to meet specific objectives. Prescribed fire can be a useful tool for maintaining wildlife habitat (Dees *et al.* 2001; Grant *et al.* 2010), reducing ecosystem vulnerability to future wildfires, achieving and sustaining resilient landscapes (Moritz *et al.* 2014; Smith *et al.* 2014; Vaillant *et al.* 2016), and reducing the severity or magnitude of smoke production from future wildfires (Ward and Lamb 1971). Prescribed fires can be used to manipulate the quantity, timing and patterns of smoke emissions (Sandberg and Dost 1990). However, all wildland fires produce a suite of atmospheric pollutants (e.g. particulate matter, carbonaceous and nitrogenous species, and ozone precursors) (Komarek 1971; Reisen *et al.* 2015) that affect atmospheric chemistry and air quality at local, regional and global scales (Damoah *et al.* 2004; Sodemann *et al.* 2011; US EPA 2012). Unlike emissions from industry and transportation, wildland fire emissions are spatially and temporally episodic and they can impair visibility and have negative short- and long-term impacts on public health (Crutzen and Andreae 1990; Bowman *et al.* 2009; Liu *et al.* 2015; Adetona *et al.* 2016). Thus, although wildland fires are inevitable and have an essential role in many terrestrial ecosystems, the smoke produced by these fires is a considerable societal concern (Bowman *et al.* 2009; Smith *et al.* 2016). Balancing the management of wildland fires in a way that preserves ecosystem function and maintains air quality to protect human health remains a substantial research and environmental policy challenge (Haikerwal *et al.* 2015; Schweizer and Cisneros 2016). Adding to this challenge is a heterogeneous mix of communities with different views of prescribed fire and tolerance to wildland fire smoke (Blades *et al.* 2014).

The development of congruent wildland fire management and air quality policies is an important topic within the United States, Australia and other fire-prone countries (Schweizer and Cisneros 2016). Although policies to manage emissions from wildland fires have been developed in some countries, multiple factors commonly make it difficult to effectively meet goals for both human health and ecosystem management (Engel 2013). Specifically, these include a deepening awareness of the health impacts of wildland fire emissions (e.g. Morgan *et al.* 2010; Caamano-Isorna *et al.* 2011; Dennekamp and Abramson 2011; Reisen *et al.* 2015) trends towards increasing population density in the wildland–urban interface (Theobald and Romme 2007; Mell *et al.* 2010), increases in amenity-based migration towards wildlands by older and thus more air pollution-sensitive populations (Shumway and Otterstrom 2001), and a projected increase in the frequency of large and high-intensity wildfires due to climate change (Westerling *et al.* 2006; Pechony and Shindell 2010; IPCC 2013). Equally, as global change causes shifts in historical fire patterns, frequencies and magnitudes of their impacts, other countries will likely seek to develop complementary policies. Achieving these goals will likely require new tools to help manage exposure to pollutants generated by wildland fires and new policies that balance the appropriate use of wildland fires and the maintenance of public health.

As countries such as the United Kingdom (Gazzard *et al.* 2016) and Canada (Hope *et al.* 2016) are recognising a new future of living with wildfires, the development of new regulations by those and other governments could be greatly aided by understanding how air quality policy and wildland fire policy have co-evolved in countries with a long history of these coupled challenges. In particular, a discussion of the history of how these policies have interacted and the consequences (intended and unintended) on the management of both ecosystems and air quality could serve in helping other countries avoid challenges involved with competing end goals of different sectors of the public.

To meet this need, we review and discuss the development of air quality and fire management policy approaches in both the US and Australia. We highlight where these sets of policies, which are often developed separately, have led to competing objectives. We discuss the interactions between these policy areas, and discuss steps towards climate change mitigation through approaches to decrease greenhouse gas (GHG) emissions. In doing so, we extend a recent study by Schweizer and Cisneros (2016) that highlighted some challenges between air quality and wildland fire management through a case study example focused on the Sierra Nevada, California. This prior study briefly highlighted the Clean Air Act (CAA) and a prior version of the Exceptional Events Rule (EER), but did not discuss detailed implications for wildland fire management and did not discuss other existing air quality regulations (Schweizer and Cisneros 2016). Similarly, Engel (2013) synthesised US wildland fire air quality policy and focused on the differences in the regulatory treatment of emissions from wildfires and prescribed fires, but provided little information on how these policies were implemented by land management. In Australia, a report on smoke and GHG management was prepared by the Australasian Fire and Emergency Service Authorities Council (AFAC 2015), but in the present paper, we provide the additional historical context and comparison with the US. For each case of the US and Australia, we provide a detailed background on the formation of wildland fire and air quality policy and the implications for other fire-prone countries are discussed.

Air quality and wildland fire policies in the United States

Since the 1950s, increased understanding of fire ecology has shifted perspectives of land managers and policy-makers in the US from fire exclusion towards fuels and fire management (Fig. 1; Pyne 1997; Stephens and Ruth 2005; van Wagtendonk 2007). This shift coincided with increased awareness of how air pollution affects human health and the development of air quality standards (Sandberg and Dost 1990; Hardy *et al.* 2001). Weaver (1968) observed that the continued emphasis on improving air quality could increase resistance to prescribed fires and since that time, policy-makers and scientists have increasingly recognised the need to manage both wildland fire and air quality.

Development of United States wildland fire policy

Although the history of wildland fire management in the US has been described elsewhere (Lewis 1985; Clark and Royall 1996; Pyne *et al.* 1996; Pyne 1997; Frost 1998), we provide a brief overview of the salient points. Following a series of impactful fires in the late 19th and early 20th centuries (Fig. 1), wildland fire was viewed as a destructive force by federal land managers and policy-makers, leading to policies and tactics promoting fire exclusion (Pinchot 1905; Pyne 1997; Rothman 2005; Stephens and Ruth 2005). These early fire exclusion efforts were limited by infrastructure and funding, leading some to allow fires to burn in remote or 'low-value' areas (Loveridge 1944). These efforts were criticised as inadequate, and in 1935, the US Forest Service (USFS) adopted a policy calling for 'the fast, energetic and thorough suppression of all fires in all locations' (Silcox 1935) by 1000 hours in the morning following detection (Loveridge 1944; Pyne 1997).

Some land managers in the south-eastern US remained proponents of prescribed fire (Johnson and Hale 2002) and a federal exemption in the late 1940s enabled prescribed burning (Pyne 1997). The broad shift away from fire exclusion began in 1963 (Fig. 1), following recognition that it had created widespread fuel accumulation and promoted future uncontrollable wildfires (Leopold *et al.* 1963). These conclusions were echoed by the emerging fire ecology community (Biswell 1963; Dodge 1972; Kozlowski 1974). This led to the US National Park Service (US NPS) formally recognising fire as a critical ecological process in 1968, and adopting a 'let-burn' policy for wildfires contained within parks that met management

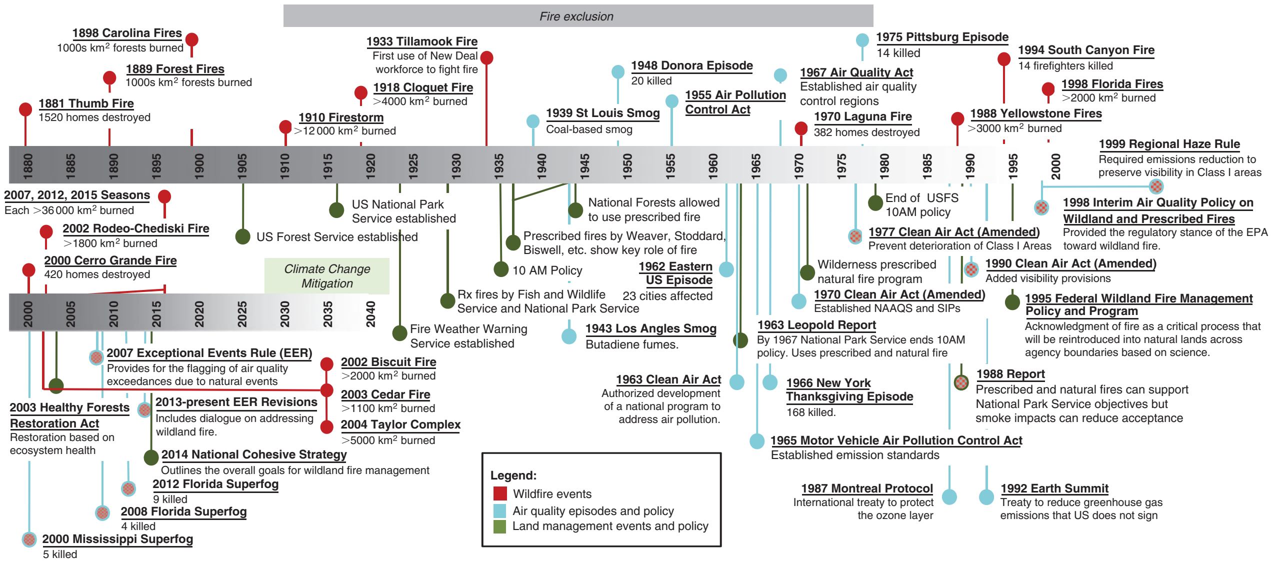

Fig. 1. Development of land-management and air quality policies within the United States and highlights of significant wildfires and air quality episodes. Citations within the figure are included in the reference list. Additional sources beyond those in main text: Lynn *et al.* (1964), Stebbings *et al.* (1976) and Baty *et al.* (1977).

objectives (van Wagtendonk 2007). A 1971 symposium organised by the USFS led to a policy shift that allowed some wildfires to burn within wilderness areas (van Wagtendonk 2007; Engel 2013).

In the late 20th century, large wildfires such as the Happy Camp fire, Yellowstone National Park 1988 fires and notable firefighter-fatality fires (Fig. 1) caused US federal land management agencies to review policies (Keiter 2006). In the 1995 (updated 2001) Federal Wildland Fire Management Policy, the US government recognised that wildland fire was an essential ecological process and that excessive fuel accumulations would require silvicultural treatments (USDI and USDA 1995; USDI et al. 2001). The Federal Wildland Fire Management Policy called for the creation of fire management plans for all burnable lands, including details on resource objectives, land-management activities and public health issues such as air quality (USDI and USDA 1995; USDI et al. 2001). This policy also highlighted improved cooperation among federal agencies and state and local governments (USDI and USDA 1995; USDI et al. 2001). The Federal Wildland Fire Management Policy remains the foundation for US federal fire management (National Wildfire Coordinating Group (NWCG) 2009).

The 2014 National Cohesive Strategy (USDA and USDI 2014), as required by the 2009 Federal Land Assistance Management and Enhancement Act (US Congress 2009), outlined the overall goals for wildland fire management: (1) restoring and maintaining landscapes, and (2) ensuring populations and infrastructure can withstand wildfire without loss of life or property (USDA and USDI 2014). This was a collaborative effort by federal, state, local, tribal and public partners and was informed by the Quadrennial Wildland Fire Review (USDA and USDI 2014; Booz Allen Hamilton 2015) and by the US National Science and Technology Council (National Science and Technology Council 2015). Although prescribed and managed fire remains a valuable tool for ecosystem management (Agee 1996; Wiedinmyer and Hurteau 2010; Arkle *et al.* 2012), the resulting emissions are regulated under the US federal air quality policies (US Congress 1990) and are increasingly affected by climate policies and international emissions agreements.

United States air quality regulatory framework for wildland fire

Until the second half of the 20th century, air quality issues in the US were primarily resolved through local laws, nuisance statutes or private litigation (Fig. 1, Table 1; Stern 1982; Sandberg and Dost 1990). As industrialisation increased, so did the number of impactful air pollution episodes, including the 1943 Los Angeles Smog Episode, the 1948 Donora episode and the 1966 New York Thanksgiving Episode (Fensterstock and Frankhauser 1968; Helfand *et al.* 2001; California Air Resources Board 2015; Fig. 1). Initial federal air quality legislation was enacted in 1955 (US Congress 1955; Kiester 1999; Seinfeld 2004) and following the 1963 CAA, Congress granted the federal government authority to resolve interstate and intrastate air pollution issues (US Congress 1963). The CAA shifted the burden of proof from public health complainants to the emitters, including land managers (Sandberg and Dost 1990), directly affecting the use of prescribed fire. For example, before the 1970s, smoke impacts from autumn prescribed burns in Washington and Oregon were not explicitly considered in the decision-making process (Sandberg and Dost 1990). However, increasing smoke management restrictions between 1970 and 1984 changed burning techniques to promote smoke dispersion (Sandberg and Dost 1990) and decreased public smoke complaints (US EPA 1978). This shift resulted from amendments to the CAA that granted authority to create National Ambient Air Quality Standards (NAAQS) and required all states and tribes to develop implementation plans to meet these standards (US Congress 1970). The CAA was further revised in 1977 and 1990 and remains the basis for current air quality regulations (Table 1; US Congress 1977, 1990).

Table 1. United States legislation action to improve air quality 1955–90 and the associated implications for wildland fire

Legislative action	Implications for air quality and smoke management
1955 Air Pollution Control Act (APCA)	• Allowed the appropriations to fund research and technical assistance for air pollution control • Provided a basis for further legislation
Bills to extend the APCA in 1959 and 1962	• Extended the terms of the 1955 Act in the early 1960s • Provided a basis on which stronger legislation could be developed
1963 Clean Air Act (CAA)	• Protected air resources by facilitating research programs to mitigate air pollution on a national scale • Provided financial and technical assistance to state and local governments to develop programs addressing air pollution • Provided the initial CAA on which subsequent amendments and regulatory authority would be based
Air Quality Act of 1967	• Authorised expanded air quality research activities • Called for the delineation of regions for determining air quality standards • Called for the study of ambient air standards and a subsequent report to Congress
1970 CAA Amendments	• Established National Ambient Air Quality Standards (NAAQS) for criteria pollutants • Required the development of State Implementation Plans (SIPs) to detail local implementation NAAQS
Executive Order 1110.2 1970	• Established the Environmental Protection Agency (US EPA) to develop and enforce air quality regulations, conduct research, support pollution reduction, and develop and recommend policy changes (Ruckelshaus 1970)
1977 CAA Amendments	• Established visibility as an air quality-related value to be protected and designated certain national parks and wilderness areas as 'Class I' areas subject to more strict standards than other areas • Authorised provisions to limit further degradation of air quality (Prevention of Significant Deterioration) • Prohibited the federal government from engaging in or supporting actions that do not conform to a State's plan to control emissions (further amended in 1990 and via the General Conformity Rule in 1993)
1990 CAA Amendments	• Established provisions for Regional Haze Rule and NAAQS • Created guidelines for attainment and state implementation plans • Developed provisions for visibility including monitoring, research, adoption of regional models and establishment of committees • Expanded visibility monitoring, research and adoption of regional models as well as providing for committees to review and report on the interstate transport of pollutant sources affecting Class I areas (1990). Created further guidelines for State Implementation Plans (SIPs)

Table 2. The United States National Ambient Air Quality Standards for fire-related criteria pollutants as of 2015

Different pollutant standards are calculated over various periods of time. Primary standards are in place to protect public health; secondary standards are in place to protect public welfare. Source: US EPA (2016*a*)

Pollutant		Standard	Averaging time	Level	Form
Nitrogen dioxide		Primary	1-h	100 ppb	98th percentile of 1-h daily maximums, averaged over 3 years
		Primary and secondary	Annual	53 ppb	Annual mean
Carbon monoxide		Primary	8-h	9 ppm	Not to exceed more than once per year
		Primary	1-h	35 ppm	Not to exceed more than once per year
Ozone		Primary and secondary	8-h	0.070 ppm	Annual fourth-highest daily maximum 8-h concentration, averaged over 3 years
Particulate matter	$PM_{2.5}$	Primary	Annual	12 $\mu g\ m^{-3}$	Annual mean, averaged over 3 years
		Secondary	Annual	15 $\mu g\ m^{-3}$	Annual mean, averaged over 3 years
	PM_{10}	Primary and secondary	24-h	35 $\mu g\ m^{-3}$	98th percentile, averaged over 3 years
		Primary and secondary	24-h	150 $\mu g\ m^{-3}$	Not to be exceeded more than once per year on average over 3 years

The US Environmental Protection Agency (US EPA) determines the NAAQS. Jurisdictions are designated as in attainment (meeting standards) or in non-attainment of NAAQS based on periodic evaluations of pollutant measurements. Policy development to attain NAAQS is largely delegated to states and tribes, who must create and maintain State or Tribal Implementation Plans (SIPs or TIPs) documenting their NAAQS-attainment actions. Wildfires and prescribed fires generate several pollutants that are regulated under the NAAQS (Table 2): particulate matter, ozone, nitrogen dioxide and carbon monoxide. Wildland fire emissions vary as a function of combustion phase, fuel properties and moisture content, among others (Hardy *et al.* 2001). The adoption of a smoke management program (SMP) to mitigate prescribed fire emissions may be included, and while not required, certified SMPs can provide some regulatory flexibility (US EPA 1998).

It is an ongoing challenge to create land-management policies that improve air quality while simultaneously providing the ecological benefits of wildland fires and decreasing risks of future wildfires; this challenge in promoting the public good has been repeatedly recognised by the US EPA (US EPA 1992, 1998; US Federal Register 1999, 2007). In the following subsections, we briefly discuss regulatory policy and rules regarding wildland fire emissions. Specifically, we will look at (i) US EPA fire and air policy and SMPs; (ii) federal conformity to NAAQS; (iii) visibility considerations, and (iv) addressing NAAQS exceedances from wildland fires.

The 1998 interim air quality policy on wildland and prescribed fires

Use of prescribed fires to limit emissions was first addressed by the US EPA in 1992 (US EPA 1992), and readdressed by the 1998 Interim Air Quality Policy on Wildland and Prescribed Fires (US EPA 1998). This policy sought to allow the use of prescribed fire, while mitigating emissions impacts (US EPA 1998) and outlining the collaborative roles of federal land managers and air regulators. This policy included recommendations to develop smoke management programs to mitigate impacts on public safety, NAAQS attainment and visibility in protected areas. As an example of the intended collaboration, the Western Governors Association (WESTAR 2015*a*) and the Western Regional Air Partnership (WRAP 2015*a*) have among their primary objectives the exchange of air quality information, and the representation of both environmental regulatory and federal land-management stakeholders. Overall, these policies highlighted the increasing importance of smoke management practices.

Federal conformity to NAAQS – the 2010 General Conformity Rule

To aid in NAAQS attainment, the General Conformity Rule prohibits federal agencies from taking actions that jeopardise a state's or tribe's ability to bring areas back into attainment of the NAAQS. This rule provides incentives to have an EPA-certified SMP, under which prescribed fires are presumed to abide by the General Conformity Rule so long as they meet requirements laid out in the 1998 Interim Air Quality Policy or an equivalent EPA replacement policy (US EPA 1998; US Federal Register 2010). States can also create a list of federal agencies and actions that are 'presumed to conform' (US Federal Register 2010). Burning near non-attainment areas in states that have neither a certified SMP nor a 'presumed to conform' list may require additional documentation from federal land managers to ensure attainment (Hardy *et al.* 2001).

Visibility considerations – Class I Areas and the Regional Haze Rule

The CAA designated 156 national parks, monuments and wilderness areas as 'Class I' areas that receive more stringent air quality protection (US Congress 1977). Impaired visibility in Class I areas mainly results from regional haze – pollutants emitted from a broad geographic area and multiple sources (USDA and USDI 2010; Hardy *et al.* 2001), making remediation difficult. For example, the 1990 CAA amendments (US Congress 1990) established the Grand Canyon Visibility Transport Commission (GCVTC 1996) to understand regional haze and develop regulatory mechanisms to improve visibility, which led to the US EPA's Regional Haze Rule in 1999 (US Federal Register 1999). The Regional Haze Rule outlined activities associated with prescribed fire that would enable its use to meet land-management goals while minimising impacts on visibility. States within the area addressed by the GCVTC were required to establish an emissions inventory and tracking system from wildland and agricultural fires and establish Enhanced Smoke Management Programs (ESMPs) for wildland fire. The ESMPs consider objectives for visibility, health, nuisance and land management, and opportunities for emissions reductions. The WRAP's Fire Emissions Tracking System (WRAP 2015*b*) required planners to describe the location, size, fuels and timing of proposed burns. Data from fire plans are combined with meteorological models to predict air quality impacts from planned burns (WRAP 2015*b*). Visibility is often included during the development of impact assessments to determine how proposed actions, including prescribed fire, may affect Class I areas (USDA and USDI 2010).

Addressing NAAQS exceedances from wildland fires – Exceptional Events Rule

Since 1998, the US EPA has applied the Natural Events Policy to assess whether uncontrollable events affected the NAAQS compliance (US EPA 1986; US EPA 1996) and whether these pollutant levels could be 'flagged' and potentially omitted (US EPA 1998). An amendment to the CAA in 2005 led to the 2007 adoption of the rule 'Treatment of Data Influenced by Exceptional Events' often referred to as the 'Exceptional Events Rule' (EER) (US Federal Register 2007; Engel 2013). The EER provided for the flagging of particulate matter and ozone exceedances for wildfires, wildland fire use (i.e. natural fires allowed to burn to meet management objectives) and prescribed fires. To be considered, the states have to document that the event was not reasonably controllable or preventable, the event affected air quality, and the event is not likely to recur at the site (US Federal Register 2007).

Robust approaches to infer apportionment between wildfires and prescribed fires remain elusive. For example, although wildland fires can be linked to ozone exceedances, the attribution of ozone exceedances to this source is challenging. Smoke plumes can block sunlight, delaying ozone formation (Jaffe and Wigder 2012); the precursor gases for ozone production, particularly volatile organic compounds, can have other large environmental sources (Simpson *et al.* 2011); and emitted NO_x can be transformed into peroxyacetyl nitrate (PAN), delaying ozone formation until PAN decomposes back to NO_x downwind (Komarek 1971; Reisen *et al.* 2015).

In 2015, the US EPA acknowledged the need for further guidance on application of the EER (US EPA 2015*a*) and in late 2016, additional guidance and a revised version of the rule became available identifying components of basic smoke management practices and additional detail addressing fire (US EPA 2016*b*). This revision reiterated recognition of the ecological role of fire, provided interpretation of the EER and provided guidance on documentation.

Other regulatory considerations – greenhouse gases, health and social impacts

Wildland fires in the US emit GHGs and aerosols (Crutzen and Andreae 1990; Ramanathan and Carmichael 2008; US EPA 2012). These emissions influence dialogue regarding prescribed fires (Hurteau and Brooks 2011; US EPA 2012). Prescribed fires can be halted if the state regulatory agency receives smoke complaints (Engel 2013). Smoke that may not affect NAAQS compliance still can impact local communities via impaired visibility (Hardy *et al.* 2001; Hyde *et al.* 2016) or dangerous driving conditions caused by decreased visibility (NWCG SmoC 2014). Consequently, managers seek to minimise nuisance smoke and emissions that will impact NAAQS compliance (Hardy *et al.* 2001). Recently, a photographic guide was developed to demonstrate to communities the potential impacts of future wildland fires and management treatments on air quality and visibility (Hyde *et al.* 2016; Fig. 2).

United States fire management responses to air quality regulation

Fire managers in the US employ several practices to mitigate air quality impacts (NWCG 2014) and allow continued use of wildland fire as a management tool. These mitigation activities typically include direct practices on the ground to decrease emissions and using topography and meteorology to direct smoke.

Prescribed fire mitigation

A key advantage of prescribed fire relative to wildfire is the ability to plan fuel consumption, smoke production and smoke trajectory. As early as 1976, regional management guidebooks provided emissions reduction techniques and methods to anticipate smoke transport (Mobley *et al.* 1976). Some of the most broadly applicable emissions management techniques have been recommended for prescribed fire planning and operations (O'Neill and Lahm 2011; Godwin *et al.* 2014) and are required for federally planned prescribed burns (NWCG 2014).

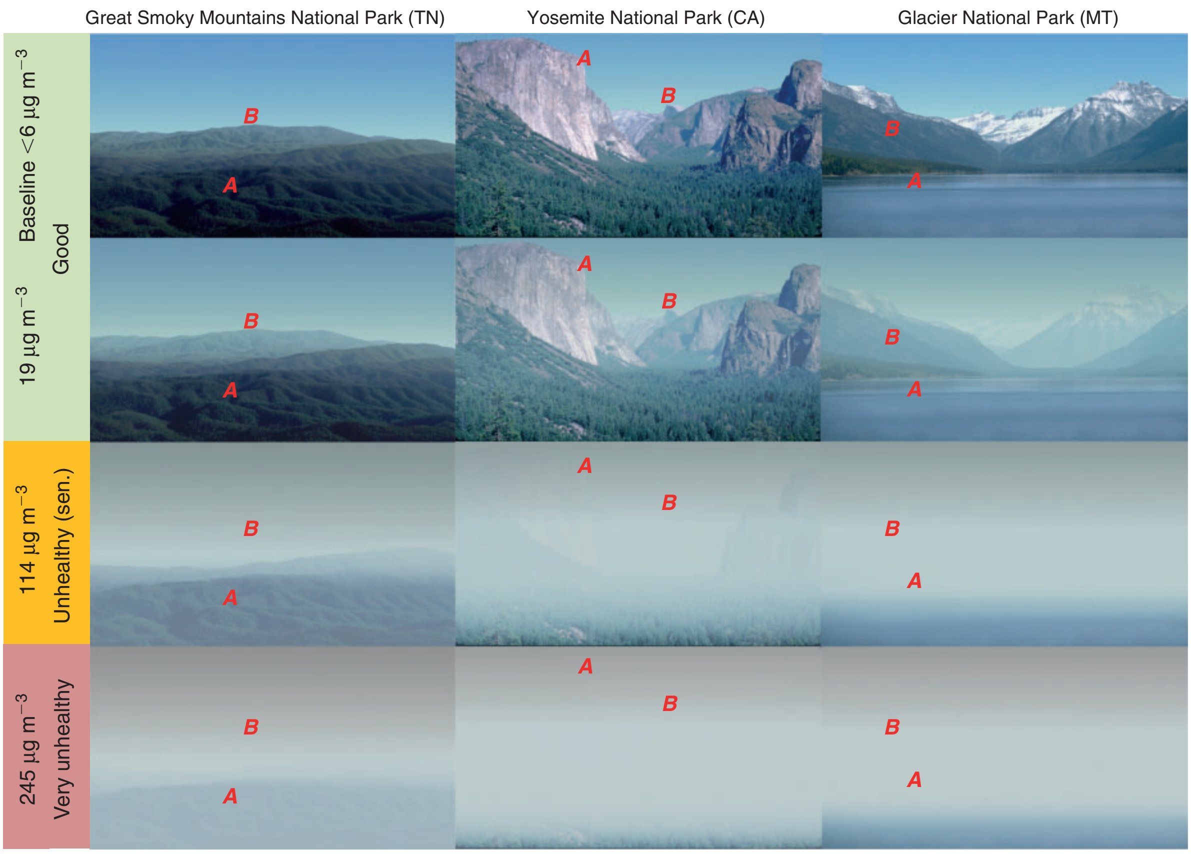

Fig. 2. Visual scenes of particulate matter ($PM_{2.5}$) concentrations from several United States National Parks. Each image represents a modelled scene using WinHaze (Molenar 2016) (see Hyde *et al.* 2016 for more details) at 40% relative humidity and particulate concentration levels characteristic of good, unhealthy for sensitive (sen.) populations and unhealthy for all populatons as used in Lipsett *et al.* (2012). Information adapted from Hyde *et al.* (2016). 'A' highlights features with 1.6–3 kilometres and 'B' denotes features between 14 and 19 kilometres from camera. TN denotes Tennessee, CA denotes California and MT denotes Montana. (For colour figure, see online version available at http://www.publish.csiro.au/nid/17.htm.)

Land managers and researchers have often collaborated to develop smoke mitigation techniques, such as USFS research efforts in the 1980s that led to improved emissions reduction strategies and meteorological planning (Ottmar 1986; Sandberg 1986). More recently, the Joint Fire Science Program committed to a US$11 million investment in smoke science (Riebau and Fox 2010; LeQuire and Hunter 2012). Other projects, such as RxCADRE (Peterson and Hardy 2016) and the Fire and Smoke Model Evaluation Experiment (FASMEE), are being carried out over several agencies and across large geographic scales. More isolated research has also aided fire managers. In the south-eastern US, late winter is well suited for the application of emissions reductions techniques, but also a time when smoke can contribute to formation of dense fogs (Achtemeier 2009) that can cause highway fatalities (Achtemeier 2002). Fog formation research led to the development of new predictive tools for fire managers (Long *et al.* 2014).

Wildfire emissions mitigation

Awareness of air quality issues, increased wildland fire activity due to climate change (Abatzoglou and Williams 2016) and population growth near wildlands (Theobald and Romme 2007) have together created the need for a wildland fire air quality response program (Lahm 2015). Together, multiple agencies have addressed this need through the training and deployment of Air Resource Advisors (Lahm 2015) who liaise with fire personnel, state agencies and communities to monitor and forecast fire and smoke conditions and impacts. This information is disseminated to help local communities mitigate smoke impacts. Land managers also work with states to develop wildfire mitigation plans before emissions impact a community. These plans, often implemented in wildfire-prone western states (State of Oregon 2013; State of Montana *et al.* 2015), outline measures to address impacts, determine trigger points and clarify agency responsibilities.

In recent years, blogs, web postings, social media and radio announcements have been employed for public communication during wildfire events. Several 'smoke blogs' provided by health and resource management agencies have included details such as fire activity, meteorological updates, health recommendations and government contact information (State of California 2014; State of Idaho 2014; State of Oregon 2014; State of Washington 2014). The US EPA's Air Quality Index is another web-based resource that provides air-quality forecasts and data that are linked to colour-coded public health advisories (US EPA 2016*c*).

Air quality and wildland fires policies in Australia

Fig. 3 illustrates the history of fire, land management and air quality policy in Australia. Under the Australian Constitution, the federated State and Territories have responsibilities for environmental management but the Federal Government can influence State and Territory laws through enforcing international treaty obligations, funding agreements and establishment of federally

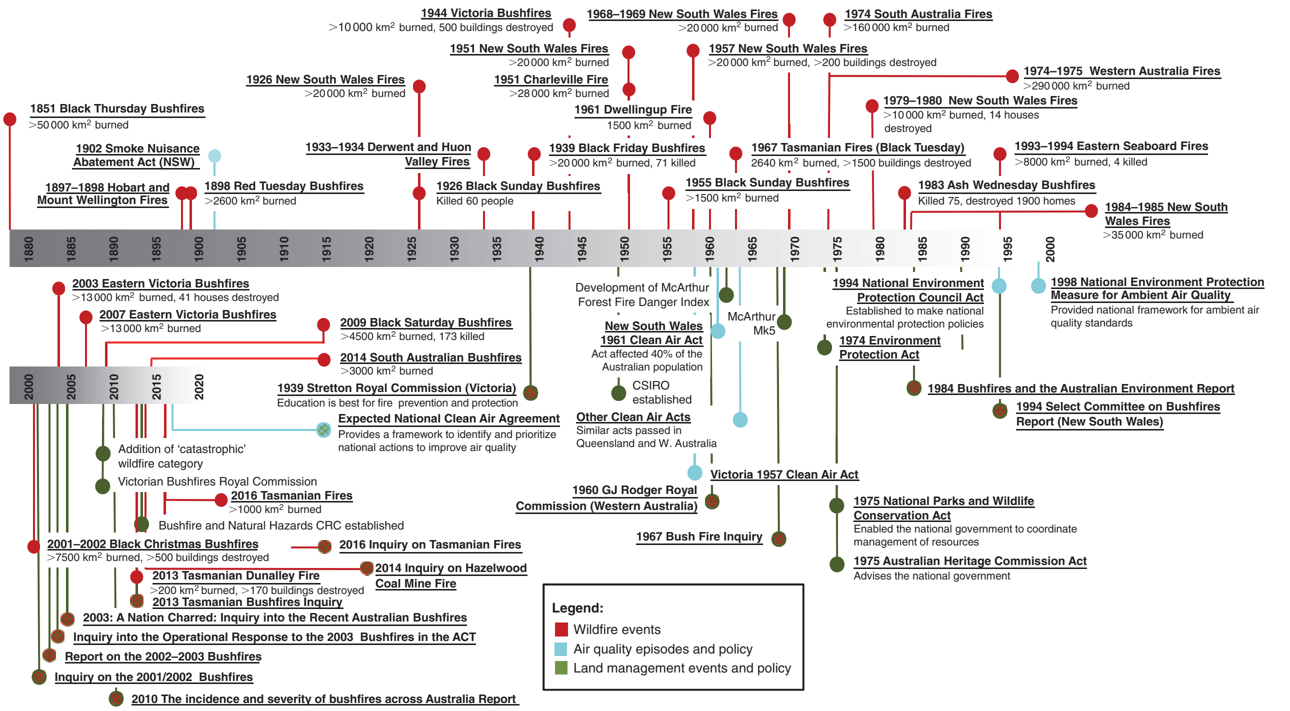

Fig. 3. Development of land-management and air quality policies within Australia and highlights of significant wildfires and air quality episodes. Citations within the figure are included in the reference list. Main source of wildland fire information obtained from Ellis *et al.* (2004), where fires that exceeded 1200 km^2 burned were included. The figure excludes Queensland fires and the 1968–75 Northern Territory fires; given these fires are remote, the smoke from them does not significantly affect communities. The timeline excludes state-based land management acts (owing to number). Additional sources beyond those in main text: New South Wales Parliament (1902, 1961, 1994, 2002); Victoria Parliament (1957, 2016); Rodger (1961); Sullivan (1965); Chambers *et al.* (1967); Australian Federal Register of Legislation (1974, 1975*a*, 1975*b*, 1994, 1998); ACT (2003); Esplin *et al.* (2003); Hunt (2014), Northern Territory Parliament (2014); Roth (2014); Price *et al.* (2015); Tasmanian Government (2016).

funded research centres, such as CSIRO (2016) and Cooperative Research Centres. An important legacy of the CSIRO fire research has been the national adoption of the McArthur Forest Fire Danger Index used to publicly communicate fire danger (Fox-Hughes *et al.* 2014; AFAC 2016), although it is recognised that this index is not suitable for all Australian environments and a new nationally agreed fire danger rating system is under review (Emergency Management Victoria 2015).

The Australian States and Territories have different lead agencies for managing landscape fire (e.g. Tasmanian Fire Service, NSW Rural Fires Service, Victoria Country Fire Authority) that involve negotiated shared responsibility with other government agencies, such as forestry and national park services. Consequently, fire management has developed idiosyncratically across Australia. These approaches have been strongly influenced by (a) different pyrogeographic conditions (e.g. tropical savannas versus temperate forests) (Murphy *et al.* 2013), and (b) the recommendation of government inquiries into major fire disasters (Fig. 3). Ellis *et al.* (2004) observed that between 1939 and 2004, common recommendations from government inquiries were: (a) placing more focus on reducing risks, including planned burning to reduce fuel loads (e.g. Victoria Parliament 1939); (b) increasing education of both adults and children; (c) increasing self-responsibility of communities and using more local knowledge in decisions; and (d) increasing resources to fire and land-management agencies. These themes reoccurred in more recent inquiries that followed the 2009 and 2013 disasters in Victoria and Tasmania respectively. A key recommendation of the Victorian 2009 Royal Commission was a mandated target of prescribed burning on public lands (Victoria Parliament 2010). Following a trial period, this approach has been replaced with an emphasis on community consultation and partnerships to reduce fire hazard regardless of land tenure. Such a 'tenure-blind' approach to fuel management also underpins the current planned burning program in Tasmania, which also grew out of the government inquiry into the disastrous 2013 Dunalley fires (Tasmanian Government 2013). It is important to note that none of these inquires have dealt with the specific issue of smoke management. The control of smoke pollution has been addressed via air pollution regulations under environmental protection legislation.

Following the establishment of individual State and Federal environmental regulatory agencies in the early 1970s, environmental regulation in Australia has become increasingly sophisticated, albeit with limited coordination among States and Territories. The Australian equivalent to the US EPA is the National Environment Protection Council (NEPC), which was established following the 1994 National Environment Protection Council Act (NEPC 2011). Although there have been various institutional changes, the core function of the NEPC remains. Since the early 1990s, there has been greater harmonisation of environmental legislation and cooperation among States, Territories and the Federal agencies (POA 1999).

In 1998, the National Environment Protection Measure for Ambient Air Quality (the 'Air NEPM') was created, providing national agreed targets for the six key air pollutants: carbon monoxide, ozone, sulfur dioxide, nitrogen dioxide, lead and particulate matter (PM) measured as particulate matter 10 µm or less in size (PM_{10}). The current standards are shown in Table 3. As part of the development of a National Clean Air Agreement, there has been a recent variation in the NEPM to include regulatory standards for particulate matter 2.5 µm or less in size ($PM_{2.5}$) and to set increasingly stringent future targets (Australian Parliament 2015; Australian Federal Register of Legislation 1998, 2016). These targets are legally binding and there has been a corresponding requirement for States and Territories to monitor and formally report the levels of these pollutants.

National air quality standards and research showing health impacts of PM have led to increased awareness of the role of wildland fire smoke in air pollution (Reid *et al.* 2016). Compared with the US air quality standards, some air NEPM standards are more stringent, yet there is also more tolerance of smoke pollution from landscape fires (Bell and Adams 2009). Originally, the NEPM allowed five daily exceedances of the 24-h 50-µm m^{-3} standard in recognition of the likelihood of bushfire smoke events. However, this rule did not specify the reason for exceedances. An 'exceptional events' rule, modelled on that in the US, has replaced the older framework of 'allowable exceedances'. Exceptional events must be investigated and reported by each State and

Table 3. Standards and goals for fire-related pollutants in Australia as established by the National Environmental Protection (Ambient Air Quality) Measure

Different pollutant standards are calculated over various period of time. Source: Australian Federal Register of Legislation (2016)

Pollutant		Averaging time	Level	Maximum number of allowable exceedances
Nitrogen dioxide		1-h	120 ppb	1 day per year
		Annual	30 ppb	None
Carbon monoxide		8-h	9 ppm	1 day per year
Ozone		1-h	0.100 ppm	1 day per year
		4-h	0.080 ppm	1 day per year
Particulate matter	$PM_{2.5}$	Annual	8 µg m^{-3}	None
		24-h	25 µg m^{-3}	None
	PM_{10}	Annual	25 µg m^{-3}	None
		24-h	50 µg m^{-3}	None

Territory Environmental Protection Authority and the information made publicly available. The definition includes PM exceedances attributable to 'bushfire' and 'jurisdiction-authorised hazard reduction burning', but not burning for silvicultural or ecological purposes. Although all exceedances must be reported, days deemed to be 'exceptional events' are excluded from determination of compliance with short-term (24-h) PM standards, but included in the determination of compliance with long-term (yearly) PM standards (Australian Federal Register of Legislation 1998, 2016; Australian Parliament 2015).

Highlights of the AFAC Report

A recent report on smoke and GHG management was prepared by AFAC, the preeminent body of the Australian and New Zealand fire management agencies (AFAC 2015). An abbreviated summary of the main elements of this report relevant to the current synthesis follows, including discussion of elements that complement the United States framework.

Although smoke from wildland fires could result in exceedances of the NEPM, and in particular the PM_{10} and $PM_{2.5}$ standards, there exists no national-level framework that can incorporate wildfire smoke into the air quality management (AFAC 2015). Three states (Victoria, New South Wales and Tasmania) and the Australian Capital Territory have specific smoke management strategies (AFAC 2015). Similarly to the US, these states use meteorological models to regulate planned (i.e. fuel reduction and forest regeneration) fires. The island state of Tasmania manages smoke emissions from planned burning through an allocation system that considers meteorological conditions, existing pollution levels in airsheds and the quantity of fuel that will be burn (through consideration of area and fuel load). In a similar approach to the United States concept of Class I areas, the Australian fire and environmental agencies seek to protect areas, or specific periods of time such as weekends and holidays, from smoke pollution and reduced visibility (AFAC 2015). The geographically small extent of the Australia Capital Territory enables qualitative assessment of the risk of smoke pollution for specific localities, including the national parliamentary precinct. Additionally, Victoria and Western Australia have developed formal processes to engage with the public to potentially identify smoke pollution concerns from planned fires. AFAC have recently proposed a smoke risk-management framework that has four key stages: strategic planning, tactical program planning, operational planning and burn operation execution. This framework is designed to help manage smoke pollution from planned burning programs in Australia and New Zealand by highlighting key decision points and risks. However, this framework is generic and is not closely coupled with current environmental regulatory and public health protection frameworks, nor does it provide an obvious pathway to coherently integrate legislation that affects smoke management.

Greenhouse gases

There is increasing consideration of the GHG emissions from wildland fires in Australia. Annual national emissions of carbon dioxide (CO_2), methane and nitrous oxide from all wildland fires are reported in accordance with the United Nations Framework Convention on Climate Change. Emissions from the frequently burnt north Australian savannas and the flammable *Eucalyptus* that dominate forests are different in terms of reporting and GHG management. The savanna fires are considered as a component of the agriculture sector for Intergovernmental Panel on Climate Change (IPCC) reporting purposes, whereas forest fires are treated as a form of land-use change. There is no clear pyrogeographic basis for this dichotomisation, as neither classification reflects the reality of fires in the ecological functioning of these landscapes. Approaches for GHG abatement include shifting savanna burning from the late dry season to early austral winter dry season to reduce emissions of methane and nitrous oxide, where it is assumed there is no net flux in CO_2 due to post-fire draw-down by regrowing vegetation. A methodology to estimate such abatement is included in federal legislation pertaining to carbon cycle management. In *Eucalyptus* forests, an approach to GHG emissions from planned burning has not been developed because of high levels of uncertainty and complexity in estimation of any abatement in methane and nitrous oxide, and the inability to include carbon dioxide given the IPCC assumptions on reabsorption of this GHG by post-fire regrowth (Bradstock *et al.* 2012). AFAC (2015) has outlined a preliminary GHG risk framework from planned burning, yet more research is required to understand fire regime effects on GHG emissions and carbon dynamics among different Australia forest types. Should Australia enter into any future international treaties to regulate GHG emissions from landscape fire, this could, in principle, substantially influence fire management practices across the nation because of the constitutional power sharing among the Federal and State and Territory governments.

Comparative lessons from the United States and Australia

There are similarities and differences in the structural characteristics of land and air quality management between the US and Australia (Sneeuwjagt *et al.* 2013). For instance, both nations have considerable areas of government-owned wildlands, but most of this government (Crown) land in Australia is controlled by State and Territory governments, whereas various US federal agencies together manage 29–85% of the land area among states in the western US (Vincent *et al.* 2014). In theory, the more localised control of land management in Australia should allow closer coordination with air regulatory agencies. Both countries have established very similar national air quality standards for the same set of six pollutants (Tables 2 and 3). In addition, measures to comply with the national air quality standards are delegated to environmental regulators at the State or Territory level. In nearly all cases, this involves institutional separation between fire managers and air quality regulators, although in Western Australia, they are within the same organisation, which is an arrangement thought to present fire managers with 'fewer hurdles to collaborations with regulators' (Sneeuwjagt *et al.* 2013). This local control is advantageous in that it allows flexibility to adapt to variation in environmental and economic drivers of air pollution. However, cross-boundary air pollution, including that related to wildland fire management, can be difficult to resolve under localised regulatory systems.

There are cultural and historical differences in attitudes towards fire in Australia and the US (Pyne 1995; Sneeuwjagt *et al.* 2013). The adoption of prescribed fires to reduce fuel loads by Australian land management agencies in the 1960s is in sharp contrast to fire exclusion policies adopted in the US (e.g. the USFS 1000 hours policy) that have left an enduring physical and cultural legacy of fire suppression. These approaches have resulted in differences in landscape fire activity in both countries. Both prescribed and wildfires have been a constant feature of the Australian landscapes since the second half of the 20th century. In contrast, there were few very large wildfires in the decades following the widespread imposition of fire suppression in the US (Figs 1 and 3), although extensive livestock grazing and favourable long-term climate patterns might also have contributed to this decline in landscape fire activity (Westerling and Swetnam 2003; Lannom *et al.* 2014).

It is possible that the higher level of background fire activity in Australia compared with the US has affected attitudes towards smoke pollution, where Australians are broadly more tolerant than North Americans (Bell and Oliveras 2006; Sneeuwjagt *et al.* 2013). These cultural differences may have affected the regulatory treatment of emissions from prescribed fires. Although ambient air quality legislation in both countries uses the 'exceedance' concept to identify when events influence the attainment of air quality standards, in the US EPA, there is a clear regulatory distinction between wildfire emissions and prescribed fire emissions (Engel 2013), whereas the Australian Air NEPM does not distinguish between these two sources of wildland fire smoke. However, as noted above, air quality management frameworks at the state level in Australia can still regulate the use of prescribed burns in an attempt to minimise health impacts, and in some cases provide clean airsheds at particular times of year, and avoid smoke pollution of specific places. Despite mounting concern about the public health impacts of wildland fire emissions, there remains limited understanding of the trade-off between wildfires and planned fires in terms of overall public health smoke exposure (Williamson *et al.* in press) Consequently, neither country has a national-scale integrated environmental framework that can be used to assess the costs and benefits associated with prescribed burning. Likewise, there remains substantial uncertainty about the consequences of wildfire and prescribed burning on GHG emissions in both Australia and the US wildlands (Hurteau and Brooks 2011; Bradstock *et al.* 2012; Bowman *et al.* 2013). Such uncertainties present important and exciting research challenges that demand transdisciplinary collaboration involving ecologists, atmospheric scientists, epidemiologists and fire managers.

Implications for other countries

In addition to the US and Australia, several other countries have significant wildland fire events and to varying degrees have developed, or are in the process of developing, air quality policies with ties to fire.

At the established policy end of the spectrum is Canada. For Canada, a detailed review of air quality policies can be found in McMillan and Foley (2014) and Canadian wildland fire management policy in the Canadian Wildland Fire Strategy (CWFS 2005). Canada's wildland fire policy and aspects of its air quality approach are similar to that of the US. The early 20th century saw a rise in wildland fire control agencies, with a recognition of prescribed fire benefits later in the century and the development of a Canadian wildland fire strategy (CWFS 2005) following large and disastrous fire seasons. The strategy was aimed in part at public community resilience and sustainable ecosystems. In 2000, all territories except Quebec adopted the Canada Wide Standards (CWS) for particulate matter and ground-level (tropospheric) ozone, and the Canadian government has developed a series of Canadian Ambient Air Quality Standards (CAAQS). The Canadian regulatory framework has a similar approach of documenting exceptional event air quality exceedances from wildland fire (CCME 2012), and considers wildfire as well as prescribed forest and grass fires from within North America conducted for security purposes, forest enhancement or wildlife habitat.

Another example of a developed approach to fire and air quality with different emphasis can be seen in southern Europe, where wildland fires are widespread and significantly affect air quality in the region (European Environment Agency (EEA) 2012). The impacts of fire in Europe are perhaps most acute in Greece, which experiences the largest average fire size in Europe (Lazaridis *et al.* 2008), destructive fires within the wildland–urban interface (Xanthopoulos 2008) and marked air quality degradation due to fires (Lazaridis *et al.* 2008; EEA 2012). Although prescribed fire has been adopted elsewhere in southern Europe over the last several decades, it remains prohibited in Greece, partially owing to public intolerance for diminished air quality caused by prescribed fires (Papanastasis 2015). Air quality regulations in Greece follow the European Union Directive 2008/50/EC. The directive establishes ambient air quality standards similar to the US NAAQS, but further impedes prescribed fire by prohibiting countries from subtracting emissions from human-caused wildland fires (accidental or controlled) within their borders in determining air quality attainment (EEA 2012).

At the emerging end of the policy spectrum is Indonesia, with the fourth largest population worldwide and many of the forest fires a result of land clearing (Simorangkir and Suamntri 2002). This has the potential to cause substantial air quality impacts like those resulting from the 2015 fires that burned 2.6 million ha (World Bank 2016). Although Indonesia established a set of national air quality standards in 1999 (Republic of Indonesia 1999), often focusing on industrial or transportation emissions (Clean Air Initiative for Asian Cities (CAI-Asia) 2010), we did not find regulations specifically targeting smoke from fires. The country's approach to fire regulation has been directed at preventing deforestation from land-clearing fires (Republic of Indonesia 1999; CAI-Asia 2010). However, the approach was difficult to implement in 2002 owing in part to weak regulations, vested interests that marginalise fire-related issues and lack of enforcement resources (Simorangkir and Suamntri 2002), and has continued to prove difficult (Clark 2016) as the regulatory environment is continuing to develop.

For countries still considering the integration of wildland fire emissions into an air regulatory framework, there are valuable lessons from the US and Australian approaches. Both systems have strength in that they established pollutant levels standards nationally, based on scientific evidence of health impacts. This approach lends a universal approach to determining standards (based on health), and consistent applicability throughout the country. In terms of addressing wildland fire, both seek to allow for wildland fire emissions through a documentation process, established after the initial air quality standards were created. This can be beneficial in accounting for the inevitability and ecological role of wildland fire, even if it necessitates additional efforts both for states gathering and preparing documentation and regulatory agencies reviewing it; through experience, it has been found that clearly outlining specific documentation requirements and continual communication among land managers and regulators can help the process to be more efficient.

Future challenges

Air quality regulations have traditionally addressed industrial or transportation emissions; these emissions are predictable in their composition, quantity, location and timing, enabling robust emission targets that are evaluated using established monitors. In contrast, wildland fires emissions are inherently variable and can strongly differ in composition, making it difficult to predict, monitor and regulate emissions. Although traditionally regulated emission sources and wildland fire emissions are both by-products of processes that can benefit society, differences between these sources make it challenging to develop policies that maximise societal benefit. First, unlike traditionally regulated sources, emissions from wildland fires are largely inevitable and will occur at some scale without human action. Second, traditional air quality policy solutions involve regulation of predominantly private actors, whereas limiting wildland fire emissions in many areas requires engagement between public agencies tasked with very different missions (Engel 2013). In the US, federal land agencies and the US EPA have agreed that continuing collaboration is vital to successfully meeting the objectives of each group for wildland fire (US EPA 1998; USDI *et al.* 2001; USDA *et al*. 2016).

It has been suggested that the regulatory distinction in the US between wildfire and prescribed fire be eliminated because it creates an environment in which beneficial prescribed fires carry more risk to managers than fire exclusion, which ultimately creates more damaging wildfires (Engel 2013). However, questions concerning this approach remain, including whether emissions differ between wildfires and prescribed fires, the management implications of treating wild and prescribed fires equally in a legal liability context, and the public acceptability of such an approach. All recent rules issued by the EPA, including the EER revision, still consider prescribed fire as anthropogenic and wildfire as natural. In Europe, the lack of any mechanisms to exclude prescribed fire emissions from air quality attainment data discourages the adoption of this tool to limit destructive wildfires.

Given the increasing evidence of smoke-related health effects (Rappold *et al.* 2012; Liu *et al.* 2015; Adetona *et al.* 2016), wildland fire emissions will likely continue to be regulated to support public health. However, future policies are also likely to address wildland impacts on GHG emissions and radiative forcing. Recent (2005) emission inventories indicate 35% of total US black carbon emissions resulted from biomass burning, including wildland fire (US EPA 2012). In the 2011 National Emissions Inventory, wildland fires were estimated to emit over 239 million tonnes of CO_2 and nearly 1 million tonness of methane (US EPA 2015*b*), one-tenth of the CO_2 and $>11\times$ the methane emitted by road vehicles (US EPA 2012). As discussed earlier, efforts are under way in Australia to modify the timing of planned fires to reduce GHG emissions, strategies that could be applied globally.

Legislation in the US has not addressed wildland fire emissions in regard to climate change. However, an executive order issued in 2013 detailed a climate action plan, including efforts to decrease GHG emissions, increase carbon sequestration and mitigate climate change impacts (Executive Office of the President 2013*a*). This plan explicitly addressed wildfire risk mitigation through fuels treatments. In a separate executive order, federal land management agencies were directed to create policies that increased carbon sequestration and climate change resilience (Executive Office of the President 2013*b*). Given the role of wildland fire in carbon cycling and ecosystem function (Hurteau and North 2009; Bradstock *et al.* 2012), these policy goals will require further recognition of fire as a necessary land-management tool.

Effective regulation of wildland fire GHG emissions necessitates an accurate understanding of those emissions. Wildland fire emission inventories require several steps, each with considerable uncertainty, including: quantification of areas and fuels burned, fire combustion phase, combustion efficiency and the emission factors (Urbanski *et al.* 2011; Larkin *et al.* 2012; Urbanski 2014). Within the US, inventories created for different purposes apply different methodologies, such as the US National Emissions Inventory (US EPA 2016*d*) and the US GHG Emissions Inventory (US EPA 2014). Discrepancies in burned area estimates can result from different reporting conventions (Wade 2014). For instance, the National Interagency Fire Center estimated 1 million ha was treated with prescribed fire nationally in 2012 (Wade 2014), whereas the Coalition of Prescribed Fire Councils reported >2.8 million ha of prescribed fires (Melvin 2012). Emissions estimates likely exhibit similar variability in Australia because they are dispersed across separate governments and agencies. Furthermore, variation among fires remains a challenge for emissions modelling. A synthesis of southern Africa fire data highlighted a clear seasonal dependence in emission factors for carbonaceous gases (Korontzi *et al.* 2003) and it is widely accepted that emission factors are highly variable by fire type and combustion phase (Hardy *et al.* 2001). Thus, mitigation of wildland fire GHG emission impacts requires a deeper understanding of wildland fire science.

Conclusions

Emissions from wildland fires are inevitable. Increasing populations in the wildland–urban interface, climate change and growing recognition of health impacts from wildland fire emissions require continued engagement among land-management agencies, air regulators and the public. Communities within fire-prone areas must either tolerate smoke or actively undertake adaptation (such as fuels management) or mitigation (such as evacuations) actions to decrease exposure (Moritz *et al.* 2014; Smith *et al.* 2016). Clearly, decisions should be made to reduce the vulnerability of sensitive groups, while minimising hazards from future wildfires.

Overall, the wildland fire management and air quality communities have together demonstrated accountability in efforts to balance air quality and ecosystem function, but additional policy, research and management actions would benefit society. The preceding synthesis has led to the conclusions that follow.

The episodic, non-stationary qualities of wildland fire, along with its presence as a natural process, pose policy challenges

Air quality standards in the US, Australia, Canada and Europe effectively regulate industrial and transportation emissions. However, as emissions from these sources have declined and the effects of both climate change and previous suppression policies on wildland fire activity have become apparent, wildland fires have become a more important source of regulated air pollutants. Because the emissions from wildland fire are both inevitable and dynamic, new regulatory approaches must be developed to simultaneously protect air quality and preserve other ecosystem goods and services that can be created by the presence of fire on the landscape. The regulatory distinction in some areas between emissions from prescribed fires and wildfires challenges land managers.

Wildland fire and its emissions are complex; continued scientific support is imperative for development of improved policies and practices

Land managers and policy-makers have power to limit emissions and mitigate air quality impacts. Over the last several decades, collaboration between researchers and land managers has created numerous tools to limit the impact of wildland fires on human wellbeing. However, there are still enormous uncertainties regarding how emissions affect human health (e.g. which components are most damaging), how emissions vary among fires, and how these emissions are transformed in the atmosphere. Although research on these topics may seem distant from wildland fire management, it is essential to the creation of new policies and procedures to prevent and mitigate the impacts of emissions. Similarly, new research is needed to better understand how air quality regulations affect the use of wildland fire as a management tool and how this limitation impacts the provisioning of ecosystem goods and services. The trade-off between air quality and other benefits to society needs to be more accurately understood. Simultaneously, land managers and fire scientists must better communicate the benefits of wildland fire to policy-makers and the public before effective policy can be created.

Policies and regulations addressing air quality, GHGs and wildland fire must keep pace with a changing environment and be accompanied by clear guidance from regulators and health professionals

Policy-makers and scientists from the land-management, air quality and public-health communities must collaboratively develop policies that effectively maximise public welfare at time scales ranging from the short (pollution events) to medium (ecosystem function, overall wildland fire emissions) and long (climate change) term. Balancing such diverse goals is a steep, but necessary, challenge. This trend is already under way with the increasing acknowledgement of the role of fire and need for collaboration expressed in documents such as the 2016 EER guidance, and the increase in smoke-related presentations at international wildland fire conferences; this approach must continue.

Land managers should incorporate the expertise of air and health professionals early in planning for prescribed burns. This would allow the generation of risk and vulnerability assessments on the degree of likely smoke exposure and the potential impacts on sensitive groups. Clearly, if prescribed burning occurs (for fuels reduction or GHG abatement), then local communities will be at a higher risk of receiving smoke exposure; pro-active strategies for the mitigation of health impacts are therefore essential to achieve broad community acceptance of these fires. Policy must keep pace with needs of GHG abatement as well as advances in the best available science and find a balance between the ecological role of fire, ensuring air quality for human health and mitigating climate change. Equally, wildfire and smoke education must keep pace with policy and science advances.

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