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Global trends in wildfire and its impacts: perceptions versus realities in a changing world

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Wildfire has been an important process affecting the Earth's surface and atmosphere for over 350 million years and human societies have coexisted with fire since their emergence. Yet many consider wildfire as an accelerating problem, with widely held perceptions both in the media and scientific papers of increasing fire occurrence, severity and resulting losses. However, important exceptions aside, the quantitative evidence available does not support these perceived overall trends. Instead, global area burned appears to have overall declined over past decades, and there is increasing evidence that there is less fire in the global landscape today than centuries ago. Regarding fire severity, limited data are available. For the western USA, they indicate little change overall, and also that area burned at high severity has overall declined compared to pre-European settlement. Direct fatalities from fire and economic losses also show no clear trends over the past three decades. Trends in indirect impacts, such as health problems from smoke or disruption to social functioning, remain insufficiently quantified to be examined. Global predictions for increased fire under a warming climate highlight the already urgent need for a more sustainable coexistence with fire. The data evaluation presented here aims to contribute to this by reducing misconceptions and facilitating a more informed understanding of the realities of global fire.

This article is part of themed issue 'The interaction of fire and mankind'.

1. Introduction

Fire has been an important factor in the dynamics of the Earth's climate and in the development of biomes since its widespread occurrence began 400–350 million years ago (Ma) [1,2]. In fire-prone ecosystems, humans have always coexisted with fire in the landscape, and its use can be seen as the first anthropogenic tool that has affected ecosystem dynamics beyond the very local scale [3]. Whether as open biomass burning or as the relatively recent practice of combusting fossil fuels in engines and power stations, fire has been a key factor in the rise of human societies [4,5]. Yet, over the past couple of centuries the traditional European perception of fire has been implemented in many parts of the world (box 1), and fire in the landscape (commonly termed wildfire, wildland fire or landscape fire) has been typically considered as 'bad' and our focus on the whole has been on eliminating or at least containing it [16–18]. The 'command and control' attitude of most Western societies neglects the fundamental role that fire has in sustaining biodiversity and ecosystem health [11,19].

The media still promote perceptions of wildfire as the enemy even in very fire-prone regions, such as the western USA or eastern Australia where managers are attempting to move away from aggressive suppression policies and residents are slowly assimilating the concept of fire as an ecological factor [11,20,21]. While the vast majority of 30–46 million km^2 of the global land surface burned per year (approx. 4% the global land surface) [22] has little direct impact on individuals and therefore does not attract wider attention, the media tend to report on the costly and sometimes tragic impacts of some wildfires, with a focus on the fate of individuals [21,23]. This is not surprising given the fundamental risk some specific fires pose for human lives, infrastructures

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Box 1. A Western-biased perception of fire.

In this paper, we discuss widely held perceptions of fire and compare them with fire data and statistics available to date. We also highlight that our scientific knowledge and social perceptions are Western biased because most available data are derived from Western societies in fire-prone countries such as the USA, Australia and Mediterranean Europe. In these countries, current policies and social perceptions share a common starting point: the German forestry school of the nineteenth century, which spread the systematic protection of forests against fire across the Old Continent and former colonies [6–8]. This 100% fire exclusion police has long proven to be impractical, unsustainable and ecologically detrimental in fire-prone regions [9,10]. Although fire management is now slowly changing, with prescribed burning also being increasingly used, policies of aggressive wildfire suppression still apply almost everywhere [7,9,11]. For example, in the USA, only 0.4% of wildfires, whether ignited by lightning or humans, are allowed to burn [11]. All others are actively suppressed. Regarding social perceptions, it is important to stress that, in many of these regions, intentional burning had been used for a very long period both by native people and settlers. Thus, in rural areas fire was understood as part of the landscape management culture [12]. However, the current general public perception is predominantly different. Until very recently, governments refused to present fire as a potential positive ecological factor out of concern that any admission of a positive role for fire would sound contradictory [9]. Smokey Bear in the USA is the best, but not the only, example of effective public awareness campaigns supporting 100% fire suppression (figure 1). Nowadays, the perception of fire in Western communities living in high fire risk areas is slowly moving towards the recognition of fire as a valuable natural factor [13]; however, in many other regions fire is still perceived by the whole society as a natural hazard with only negative implications. This Western perception of fire currently dominates the world and is thus the focus of this paper. It is, however, not the only one. In this same issue, other contributions discuss societies which have long co-existed with fire and continue to do so sustainably, such as the aboriginal people of the Western Desert of Australia [14] or indigenous communities in Venezuela, Brazil and Guyana [15].

(*a*) (*b*)

Figure 1. Public awareness campaigns supporting total exclusion of fire from our forests have driven largely our current perceptions of fire. For example, (*a*) Smokey Bear has been the American champion against fire since the 1950s; (*b*) the 'all against fire' campaign in Spain during the late 1980s and early 1990s also had wide national relevance.

and the value of commodities such as forest plantations, yet this type of media coverage can be a barrier to expand the notion of our need of learning to coexist with fire [24,25]. Numerous reports, ranging from popular media through to peer-reviewed scientific literature, have led to a common perception that fires have increased or worsened in recent years around the world [11,26–29]. Where these reports are accompanied by quantitative observations, they are often based on short timescales and regional data for fire incidence or area burned, which do not necessarily reflect broader temporal or spatial realities.

Unlike other natural hazards such as earthquakes or volcanic eruptions, fire is perceived as an avoidable risk and enormous resources are directed towards fire suppression efforts, particularly in the more developed world [9]. Yet the now widely acknowledged consequence that fire suppression often comes at the cost of an increased risk of more severe or extensive future fire within fire-prone landscapes [30] has to date only led to limited changes to fire suppression practice in most regions [11].

The aim of this paper is to illuminate the discrepancies between the perceptions about global fire against the quantitative realities that have emerged through research on landscape fire occurrence and its impacts on society as a whole. Achieving a more balanced and realistic perspective about fire occurrence, its risks and impacts among fire specialists, decisions makers and the wider public is perhaps the most critical step towards regaining a more sustainable coexistence with landscape fires.

2. Has fire increased in many regions around the globe?

Analysis of charcoal records in sediments [31] and isotope-ratio records in ice cores [32] suggest that global biomass burning during the past century has been lower than at any

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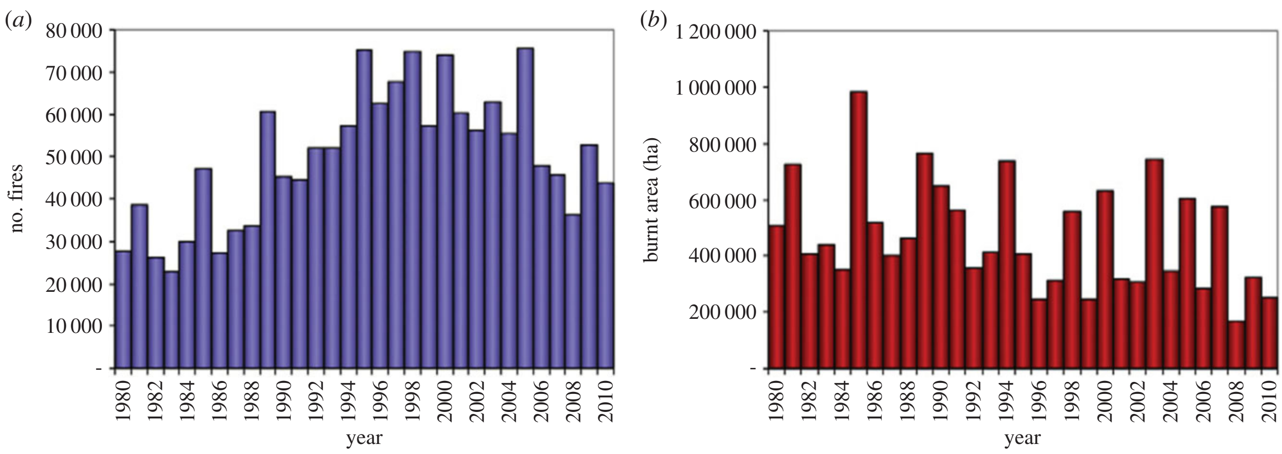

Figure 2. Wildfire occurrence (*a*) and corresponding area burnt (*b*) in the European Mediterranean region for the period 1980–2010. Source: San-Miguel-Ayanz *et al.* [37].

time in the past 2000 years. Although the magnitude of the actual differences between pre-industrial and current biomass burning rates may not be as pronounced as suggested by those studies [33], modelling approaches agree with a general decrease of global fire activity at least in past centuries [34]. In spite of this, fire is often quoted as an increasing issue around the globe [11,26–29]. One reason for this apparent contradiction may be that the global extent of fire is not necessarily correlated with impacts on human society as explored in §3. Another reason may be that our wider perception of fire is shaped by some widely publicized regional trends and a lack of discrimination between reported fire activity parameters. An important distinction regarding the latter is that between area burned (i.e. total ha or km^2) and fire occurrence (i.e. the number of fires for a given area and period). Recent trends in area burned can now be derived from satellite observations and national records with reasonable accuracy at regional and global scales [35,36]. Trends in occurrence, however, are less reliable as recording efforts and methods vary between regions. A striking example where the lack of discrimination has led to contrasting perceptions is that of fire occurrence and associated area burned in the Mediterranean region in the past three decades (figure 2). There was indeed an increase in the number of fires from the early 1980s to the late 1990s. However, the past three decades have been characterized by an overall decrease in area burned, and also a decrease in the number of fires from mid-2000 (figure 2) [37,38]. This is often not recognized even within the scientific community, with some authors continuing to underpin the importance of their fire-related research with an increase of fire in this region [16,39].

Area burned is perhaps the most commonly used parameter when fire trends are being examined. It is a relatively simple and globally relevant parameter and it underpins estimations for carbon emissions by wildfire [22]. A summary of global trends in area burned during the twentieth century is given in Flannigan *et al.* [40]. During the first half century, the global average area burned decreased somewhat by about 7% [41]. This was largely attributed to human factors, such as increased fire prevention, detection and fire-fighting efficiency, abandonment of slash-and-burn cultivation in some areas and permanent agricultural practice in others. During the second half of the past century, this trend reportedly reversed with a 10% increase in global area burned. However, this trend was not reflected everywhere, and there are regional variations and substantial uncertainties [40]. Overall, this increase in the latter half of the past century has been attributed to land management changes including increases in deforestation fires in the tropics [41], but it may also partially reflect a 'return' to a more 'normal' fire regime in areas where fire had been suppressed [40].

The availability of satellite data now allows a more consistent evaluation of temporal patterns in area burned. Thus, from an analysis based on MODIS burned area maps between 1996 and 2012, Giglio *et al.* [35] present some rather notable outcomes. In contrast to what is widely perceived, the detected global area burned has actually decreased slightly over this period (by 1% yr^{-1}). A more recent global analysis by van Lierop *et al.* [36], based primarily on nationally reported fire data supplemented by burned area estimates from satellite observations, shows an overall decline in global area burned of 2% yr^{-1} for the period 2003–2012.

At coarse regional scales, overall trends for the period 1996–2012 are rather contrasting [35]. For example, data for Europe and Australia/New Zealand show a strong decline in area burned of 5% yr^{-1}, despite the latter region experiencing the largest annual area burned in the final year of the observation period. In contrast, for Southeast Asia, the Middle East and boreal North America the estimated area burned increased by 3–4%. For temperate North America the very small increase in area burned (0.1% yr^{-1}) estimated by Giglio *et al.* [35] over this period may seem surprising when compared with the widely reported increase in area burned for the USA [42] and particularly the western USA in recent decades [43–46]. This discrepancy may at least in part be because (i) the region used in Giglio *et al.*'s analysis excludes the boreal and drier southeastern zones of the USA, and (ii) area burned in the studies focused on the USA [42–46] is based on national and regional fire statistics produced using a variety of methods. These statistics need to be viewed with some caution when examining trends as annual reporting methods and biases have undergone changes over time [47]. Indeed, according to national statistics for the USA, while area burned by prescribed fire has changed little overall since reporting began in 1998 (10 year average: 8853 km^2), area burned by wildfires has seen an overall strong trend of increase by over 5% yr^{-1} over the period 1991–2015, with 2015 exceeding 40 000 km^2 burned for the first time during the past 25 years (figure 3). This

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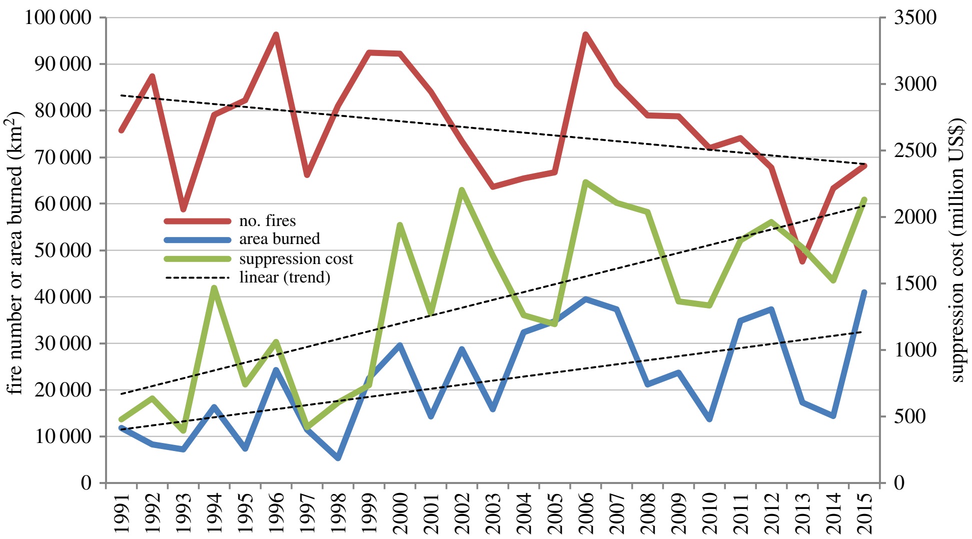

Figure 3. Area burned, number of fires and suppression costs (inflation adjusted to 2016 equivalent) for the USA with linear trend lines (1991–2015). Data: National Interagency Fire Center [48].

increase has been accompanied by an overall decline in the number of fires (figure 3). This suggests a general trend of fewer, but larger wildfires, which is also highlighted for forests in the western USA by Westerling for the period 1983–2012 [46]. However, caution is advised when considering the relative rates of change for area burned. The comparatively brief periods of observation discussed here are strongly influenced by regional interannual variability and are too short to be indicative of longer-term trends. For example, if only the past 16 full reporting years for the USA are considered (2000–2015), where annual area burned ranged between 14 284 (2001) and 40 975 km^2 (2015), the overall annual increase has been less than 1% [48]. Longer-term records can indeed reveal rather different perspectives. For example, for the Californian Cascades and Sierra Nevada, Mallek *et al.* [49] suggest that 'modern' (1984–2009) annual area burned was only 14% of that burned annually prior to European settlement (approx. 1500–1850). In addition to climate, changes in vegetation patterns and fire regimes also play an important role here and are discussed in the context of fire severity in §3a.

Thus, while there are clearly some noteworthy trends in area burned for specific recent periods and regions, the general perception of increasing fire around the world is not supported by the data available to date. This does not withstand the observation of increasing fire season length in some areas [50], which is an important contributor to the increase in area burned during this century in the northwestern USA [43,46], boreal Canada and Alaska [51,52]. A future lengthening of the fire season is also anticipated for many other regions of the globe, with a potential associated increase of fire activity [19,53–56]. It is, however, important to recognize that in addition to direct climatic factors, other factors such as fuel availability and human influence will also strongly affect future fire activity [57,58].

Thus the widespread use of limited datasets or excessive extrapolation of short-term regional trends may go some way in explaining the widely held view of generally increasing fire around the world. The wider impacts of fire on society examined in §3b–d, however, may be even more relevant in driving the overall perceptions of fire trends.

3. Have fire impacts increased in many regions around the globe?

(a) Fire intensity and severity

While the trends in area burned explored above have implications for the effects of fire on global carbon emissions, ecosystems and society, the spatial extent of burning is not always closely linked to the impacts of a fire. From a perspective of fire ecology or risk to infrastructures, the intensity of a fire (i.e. its rate of energy output), its severity (its ecosystem impacts) and its spatial patterns (degree of patchiness) may be more important than the total area burned. For example, the degree of vegetation consumption, the depth of burning into the organic and mineral soil, and the proximity of areas less affected or not by fire are key in determining the length of time for a burned area to 'recover'[1] [3,61–63]. The notion that fire intensity and severity have increased in recent years pervades media reports and some of the literature [11,64–66]. Whether or not this is the case is not easy to ascertain given that these parameters and associated trends are much more difficult to determine compared with area burned. All else being equal, fire intensity can indeed be expected to increase with air temperature [67], and it can be deduced that areas that are experiencing higher atmospheric temperatures in the fire season associated with global warming would experience more intense fires. For example, the catastrophic 2009 Black Saturday fires of Victoria (Australia) were reportedly associated, among other factors, with unprecedented high atmospheric temperatures (since measurements began) and fire intensity [68]. Whether or not this extreme event signifies a trend or may simply be the result of longer-term natural variability in fire behaviour remains an open question. Indeed, it has subsequently been suggested that the fire weather potential witnessed during Black Saturday and the associated level of fire intensity was not unprecedented in southeastern Australia [69].

Few studies exist that have explicitly examined trends in fire severity. These have mainly focused on the western USA, an area where there are particular concerns about

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Box 2. Good fire, bad fire?

Fire has long been a natural factor in many ecosystems around the world, from boreal forests to tropical savannas [76,77]. In these systems, fire is a necessary perturbation to preserve ecosystem health and stimulate rejuvenation [78,79]. Each ecosystem is adapted to a specific fire regime (i.e. fire type and recurrence), which could be understood as 'good fire'. However, when the fire regime moves away from the established one (e.g. owing to human influence), ecosystem resilience to fire may be surpassed [79]. The resulting long-lasting damage to the ecosystem would thus be caused by 'bad fire'. From an ecosystem perspective, it is therefore relatively easy to distinguish between 'good' and 'bad fire', although this is a simplification as ecosystems are dynamic entities which evolve and change [60]. Notwithstanding this, a more complicated picture arises when considering the human perspective. An ecologically 'good' stand-replacing fire in a fire-dependent forest, essential for forest regeneration, will be viewed as a 'bad fire' when it results in losses of homes or lives, or perhaps even by it resulting, in the short-term, in a black and desolate landscape. Equally, an ecologically 'bad' fire in a heathland, occurring too soon after the last one for full ecosystem recovery, can indeed be perceived as a 'good' fire for the landowner whose intention is to convert the heather into grass. Often a range of different perceptions comes into play, complicating even more the full picture, as highlighted in this issue by Davies *et al.* [80] in relation to the role of fire in UK peat and moorland management. Prescribed burning there is strongly supported by land managers, whereas opposition from the general public is a growing trend. An example of unequivocally 'bad fires', which is of global concern, is the recurring problem of peat fires in Southeast Asia. These are a consequence of land use changes and have enormous impacts on air and water quality, human health, ecosystem resilience and the global carbon cycle [81]. In September 2015, Indonesia's peat fires emitted carbon at a rate of 15–20 million tonnes per day, well above the daily carbon emissions of the whole American economy [82]. In most cases, however, whether a fire is considered 'good' or 'bad' will depend on its context, which can be ecological, social, economic or a combination of all. It is the role of the scientific community to provide an objective basis for society to understand and judge the consequences of the choices we make in how we manage, modify and coexist with fire.

increased fire activity [42,70]. Examining trends from 1984 to 2006 for large ecoregions in the north- and southwest USA, Dillon *et al.* [71] found no significant increase in the proportion of annual area burned at high severity for five of the six regions considered, with the southern Rockies being the exception. For the Sierra Nevada region (California), which was not covered in the previous study [71], Hanson & Odion [72,73] found no general increase in fire severity within the period 1984–2010. Considering ten national forests in California for the same period, Miller & Safford [74] found a significant increase in burn severity for yellow pine–mixed conifer forests. They attribute this largely to decades of fire suppression and other management practices rather than climate, which have led to major changes in forest composition and structure, increases in density and fuel-loading, and hence fire behaviour. Covering the much larger area of the dry forest landscapes of the western USA, including large parts of those examined in the aforementioned studies, Baker [75] found that the rate of high-severity fire in the period 1984–2012 was within or below that of historical century- to millennial-scale estimates.

Thus, while there is evidence of a recent increase in proportional fire severity for a specific forest type in California, these independent studies do not support the notion of an overall increase in fire severity over the past few decades in the fire-adapted forested landscapes in the western USA. Indeed, a longer term perspective focused on the Californian Sierra Nevada and Cascades by Mallek *et al.* [49] suggests that the annual area burned at high severity between 1984 and 2009 was only half that prior to European settlement (approx. 1500–1850), associated with an overall smaller area burned compared to pre-European times. Whether or not the overall lack of change in burn severity applies also to other regions where perceptions of increases in fire severity exist too has to remain unanswered until robust data emerge to test this notion.

(b) Impacts on society: direct effects on people

While the ecological impacts of fire or their interactions with climate are of concern to scientists, natural resource managers, policymakers and the public, policy and public perception regarding fire in the landscape is primarily shaped by the impacts of fire on people and society (box 2). Lives lost, together with direct damage to homes and other infrastructures create wide media attention and are probably of greatest importance here. For example, the Black Saturday fires of 2009, in which 173 people lost their lives, shook Australian society and led to major reconsideration of landscape fire related policy [68]. These and other tragic losses to lives from fire may or may not have been preventable, but should be also seen in perspective to other risks to lives. When considering some of the extreme landscape fires as a form of natural disaster, the number of deaths is actually relatively low compared with other natural disaster types. For example, data by the Emergency Events Database (EM-DAT)[2] suggest that over the period 1901–2014 3753 people have been killed by wildfire, compared with over 2.5 million from earthquakes and nearly 7 million from floods [83]. These figures are likely to be inaccurate and substantial underestimations of direct deaths from fire. For example, the EM-DAT reports 21, 35 and 17 deaths for 2012, 2013 and 2014, respectively, whereas data collected for recent years by the Global Fire Monitoring Centre report 215, 209 and 217 fatalities from landscape fires for the same years [84]. Irrespective of whether direct annual deaths number in the tens or the hundreds, they indicate a comparatively low risk of death as a result of fire compared with that from other natural disaster types (table 1), particularly considering that approximately 4% of the global vegetated land surface burns every year.

It is also worth noting that many of the deaths recorded as a result of landscape fires have indirect 'medical' or operational causes. For example of the 26 total landscape fire deaths recorded in the USA in 1999 [85], only one was a direct fire

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Table 1. Global comparison of human and economic losses derived from wildfire, earthquakes and flood disasters from 1901 to 2014. (Source: EM-DAT 2015 [83].)

	wildfires	earthquakes	floods
no. of events	387	1291	4481
people killed	3753	2 574 627	6 947 908
people injured	6812	2 614 875	1 329 923
people affected (million)	6	190	3604
risk of death (%)[a]	0.06	1.4	0.02
total direct damage (million US$)	54 828	774 771	681 427
cost per event (million US$)	142	600	152
cost per person affected (US$)	9138	4078	189

[a]No. of fatalities per no. of people affected (%).

death (burnover), nine were due to heart attack, and other causes included crushing by engines and electrocution. Unsurprisingly, fire fighters are at greatest risk from fires, particularly in regions where fire suppression involves the use of personnel on the ground in topographically complex terrain. The deaths of 19 wildland firefighters in Arizona in 2013, who became entrapped in steep terrain under changing fire behaviour [86], serve as a recent tragic example. Data from the USA show a total of 338 firefighter fatalities between 1977 and 2006 [87]. Additional deaths occur in training, and road and aircraft accidents. Among these there are no clear temporal trends in wildland fire deaths, except when considering those from aircraft crashes which have risen, probably owing to the increased use of aircraft in wildland firefighting over this period [87]. A study examining all recorded wildland fire fatalities in Spain between 1980 and 2010 reported 241 deaths of which 169 were firefighters and with no increasing or decreasing temporal trend [88]. Considering the reported global direct death toll from landscape fire 'disasters' between 1977 through to 2014, no clear trend emerges either, with large fluctuations between years ranging from zero in 1990 to a maximum of 266 in 1997 [83].

(c) Impacts on society: direct economic impacts

Human losses aside, the direct financial costs, such as the damage to homes and other infrastructures, often dominate the perception of the fire impacts and an increase in these is often highlighted in the media [89–91] or scientific papers and reports [92–94] (see also box 2). The data on fire disasters with continuous annual records of economic damage (1987–2014; [83]) give annual global values (adjusted to 2015 US$ value) ranging from US$4.6 million to US$12 318 million (annual average US$2677 million), showing no apparent temporal trend. These estimates of losses, however, only include damage to property, crops and livestock and do not reflect losses from fire events not classified as disasters.[2] Other important economic parameters not included here are the costs arising from human losses, injuries and longer-term health implications [95]. Furthermore, fire suppression costs are not considered in these figures. These can be very substantial (figure 3). For example, Greece, France, Italy, Portugal and Spain together invest €2500 million each year in fire management, with most of this budget dedicated to fire detection and suppression [16]. This is similar to the estimated global average annual losses from fires reported by EM-DAT for 1987–2004. Canada spends an average of US$ 531 million annually on fire prevention and suppression (2000–2010) [96]. There is limited data available from most countries to examine any global temporal trends.

For the USA, figure 3 shows suppression costs (adjusted to 2016 US$ rates) in relation to the number of fires and area burned during the past 25 years. While the area burned has seen an overall increase of approximately 5% yr^{-1} (see also §2), suppression costs have overall increased by approximately 1.5 times that rate. It is not clear to what degree this trend is (i) representative of any trends elsewhere in the world, and (ii) has resulted in a concomitant reduction in the actual area burned. The fact that the period of 2000–2016 has seen an increase of less than 1% yr^{-1} in inflation adjusted suppression costs, which is similar to the rate of increase in area burned over the same period, indicates that the preceding period of a relative increase in resources allocated to suppression in the 1990s was followed by a levelling off of suppression expenditure per unit area affected. That said, area burned is perhaps not the most important factor to consider when examining suppression cost in the USA. Of greater relevance may be the increasing population density and hence need for fire suppression in the wildland–urban interface (WUI). For example, in the western states of California, Oregon and Washington, housing in the WUI comprised 61% of all new homes built during the 1990s, and 43% of the total housing in the region [97]. Given that 2.9 million American homes are in areas with fire return intervals of 100 years or less [97], an increase in suppression need would be expected even if the area burned had remained unchanged. Increased housing in the WUI may be a reason why the American continent is leading the global 'league table' (table 2) in terms of total economic damage over the period 1984–2014. Building in the WUI will also have resulted in more people experiencing fire, which may be associated with greater media coverage of fire from these areas.

(d) Impacts on society: indirect impacts

In addition to direct impacts on people and economic losses, fires also have other substantial effects on society through indirect impacts. Post-fire environmental effects such as accelerated flooding, soil erosion, mass movement and pollution of water bodies are among the most costly impacts on society [3,62,63]. Other important indirect effects are the longer-term health implications [95]. A notable example of this is how smoke from landscape fires has historically, and is currently, contributing to premature deaths among the world population [98]. Estimates for the period 1997–2006 suggest these to be in the region of 340 000 per year [99]. These figures are orders of magnitudes greater than direct deaths from fires (§3b). Other indirect social impacts include disruptions to social processes and functioning, such as disruptions to road and air traffic, and closure of businesses during and immediately after the fire, or even long-term reduction of tourism, aesthetic value of the landscape or home values [100]. Catastrophic fires can even change social dynamics

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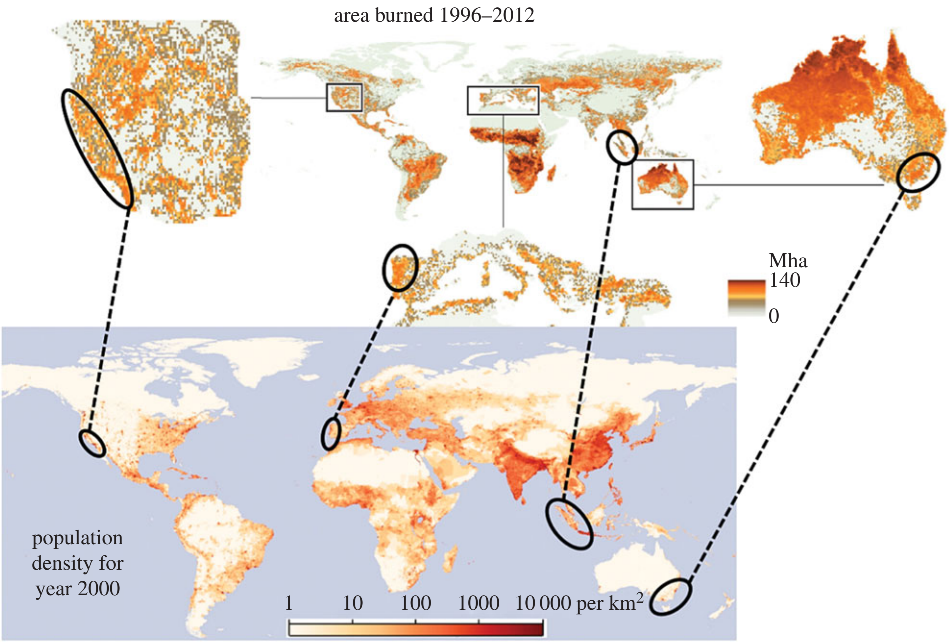

Figure 4. Global area burned with enlarged sections of the globe (1996–2012) and global population density with examples where regions with high proportions of area burned coincide with high population densities. (Based on and modified from Moritz *et al*. [19] and NASA (http://neo.sci.gsfc.nasa.gov/view.php?datasetId=SEDAC_POP).)

Table 2. Human and economic losses from wildfire 'disasters' by global region from 1984 to 2013. Costs are based on the actual value of US$ in a given reporting year. (Source: EM-DAT 2013 [83].)

	no. events	people killed	total people affected	death rate/event	economic costs (million US$)
Africa	25	272	21 672	11	440
America	118	234	1 229 175	9	25 229
Asia	50	748	3 188 257	30	11 892
Europe	89	462	1 295 562	18	12 619
Oceania	21	224	74 320	9	2121
total	303	1940	5 808 986	78	52 301

and the way people interact with each other and with the landscape [100]. Efforts are increasing to examine these indirect impacts more closely as they are currently only poorly understood and quantified [100]. It is therefore not possible here to explore any trends or their potential effects on people's perceptions.

4. Synthesis and conclusion

We have shown here that the widely held perception of increasing fire and fire impacts at the global and some regional scales is not well supported by the realities that the available data show. We do not question that fire season length and area burned has increased in some regions over past decades, as documented for parts of North America, or that climate and land use change could lead to major shifts in future fire consequences, with potential increases in area burned, severity and impacts over large regions [19,50,53]. The data available to date, however, do not support a general increase in area burned or in fire severity for many regions of the world. Indeed, there is increasing evidence suggesting that there is overall less fire in the landscape today than there has been centuries ago [34,101], although the magnitude of this reduction still needs to be examined in more detail [33].

Furthermore, the data evaluated here do not support the perception of increasing direct losses from fire. Over the past decades there is no clear trend of increasing direct losses such as losses of life or infrastructure. While any fire-related death can be seen as one too many, at least the risk of direct death from fire for the population as a whole is low compared with other natural hazards. From the data available for the USA covering the past 25 years, it is clear that suppression costs have increased substantially (figure 3). This increased expenditure and effort in the USA will most likely have saved many lives while it also led to the loss of others. Increases in suppression expenditure may, at least in part, be driven by a concern of worsening fire situation. The media are dominated by reports from fires where lives are lost or at risk, and these are typically from fire-prone regions exhibiting high population densities (figure 4). The increased population density in the WUI over past decades, for example, may itself have resulted in increased media reports. It is important to highlight that there is likely to be a bias in reporting of losses

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for Western countries given that the largest number of people affected by fire and losses of life appears to be elsewhere (i.e. Asia; table 2 and box 1).

Perhaps rather than a 'wildfire problem' that has worsened globally in recent decades, the negative, and sometimes tragic, consequences of fire themselves may be gaining wider public attention and, therefore, recognition. The fact that nowadays the latest news reports about disasters from around the world are readily available to large parts of the population may be a contributing factor. What is not spreading equally well is the recognition that fire is a fundamental natural ecological agent in many of our ecosystems and only a 'problem' where we choose to inhabit these fire-prone regions or we humans introduce it to non-fire-adapted ecosystems [3]. The 'wildfire problem' is essentially more a social than a natural one.

The warming climate, which is predicted to result in more severe fire weather in many regions of the globe in this century [53] will probably contribute further to both perceived and actual risks to lives, health and infrastructure. Therefore, the need for human societies to coexist with fire will continue, and may increase in the future [19]. We thus need to move towards a more sustainable coexistence with fire. This requires a balanced and informed understanding of the realities of wildfire occurrence and its effects. It is hoped that the data and discussion presented here, together with the other contributions in this special issue, will reduce misconceptions about fire and assist in providing this understanding.

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Endnotes

[1]The concept of the 'post-fire recovery window' or 'window of disturbance' can be viewed as the time it takes for ecosystem properties such as biomass, biodiversity, soil characteristics or the hydrological balance to return to a pre-fire status [59]. This assumes that fire is an episodic or even rare disturbance event. A more appropriate view in fire-adapted ecosystems is that fire is a natural process that is part of a natural cycle between fire and post-fire recovery conditions with varying recurrence [60].

[2]EM-DAT is a global database on natural and technological disasters which fulfil one or more of the following four criteria: (i) 10 or more people dead, (ii) 100 or more people affected, (iii) declaration of a state of emergency, (iv) call for international assistance [83]. It therefore excludes damaging landscape fire events where less than 10 fatalities have occurred or less than 100 people have been affected. Lives lost and economic damage based on EM-DAT reported here are therefore likely to be an underrepresentation of actual global values.

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