Received: 5 November 2021 | Revised: 24 February 2022 | Accepted: 19 March 2022

DOI: 10.1111/geb.13499

PERSPECTIVE

Global Ecology and Biogeography — A Journal of Macroecology

WILEY

What do you mean, 'megafire'?

Grant D. Linley[1] | Chris J. Jolly[1,2] | Tim S. Doherty[3] | William L. Geary[4,5] | Dolors Armenteras[6] | Claire M. Belcher[7] | Rebecca Bliege Bird[8] | Andrea Duane[9] | Michael-Shawn Fletcher[10,11,12] | Melisa A. Giorgis[13] | Angie Haslem[14] | Gavin M. Jones[15,16] | Luke T. Kelly[17] | Calvin K. F. Lee[18] | Rachael H. Nolan[19,20] | Catherine L. Parr[21,22,23] | Juli G. Pausas[24] | Jodi N. Price[1] | Adrián Regos[9,25,26,27] | Euan G. Ritchie[28] | Julien Ruffault[29] | Grant J. Williamson[20,30] | Qianhan Wu[18] | Dale G. Nimmo[1]

[1]The Gulbali Institute, School of Agricultural, Environmental and Veterinary Sciences, Charles Sturt University, Albury, New South Wales, Australia

[2]School of Natural Sciences, Macquarie University, Sydney, New South Wales, Australia

[3]School of Life and Environmental Sciences, University of Sydney, Sydney, New South Wales, Australia

[4]Department of Environment, Land, Water and Planning, Biodiversity Division, Biodiversity Strategy and Knowledge Branch, East Melbourne, Victoria, Australia

[5]Centre for Integrative Ecology, School of Life and Environmental Sciences, Deakin University, Burwood, Victoria, Australia

[6]Landscape Ecology and Ecosystem Modelling - ECOLMOD, Departamento de Biología, Facultad de Ciencias, Universidad Nacional de Colombia, Sede Bogotá, Colombia

[7]wildFIRE Lab, Hatherly Laboratories, University of Exeter, Devon, UK

[8]Department of Anthropology, Pennsylvania State University, State College, Pennsylvania, USA

[9]Forest Science Center of Catalonia, Solsona, Spain

[10]School of Geography, Earth and Atmospheric Sciences, The University of Melbourne, Melbourne, Victoria, Australia

[11]Indigenous Knowledge Institute, The University of Melbourne, Melbourne, Victoria, Australia

[12]Australian Research Council Centre of Excellence for Australian Biodiversity and Heritage, The Australian National University, Canberra, Australian Capital Territory, Australia

[13]Cátedra de Biogeografía, Departamento de Diversidad Biológica y Ecología, Facultad de Ciencias Exactas Físicas y Naturales, Universidad Nacional de Córdoba, Córdoba, Argentina

[14]Research Centre for Future Landscapes, Department of Ecology, Environment and Evolution, La Trobe University, Melbourne, Victoria, Australia

[15]US Department of Agriculture – Forest Service, Rocky Mountain Research Station, Albuquerque, New Mexico, USA

[16]Biology Department, University of New Mexico, Albuquerque, New Mexico, USA

[17]School of Ecosystem and Forest Sciences, University of Melbourne, Parkville, Victoria, Australia

[18]School of Biological Sciences, University of Hong Kong, Hong Kong, China

[19]Hawkesbury Institute for the Environment, Western Sydney University, Penrith, New South Wales, Australia

[20]NSW Bushfire Risk Management Research Hub, Wollongong, New South Wales, Australia

[21]School of Environmental Sciences, University of Liverpool, Liverpool, UK

[22]Department of Zoology & Entomology, University of Pretoria, Pretoria, South Africa

[23]School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Wits, South Africa

[24]Centro de Investigaciones sobre Desertificación (CIDE-CSIC), Valencia, Spain

[25]CIBIO-InBIO—Centro de Investigação em Biodiversidade e Recursos Genéticos, Universidade do Porto, Vila do Conde, Portugal

[26]BIOPOLIS Program in Genomics, Biodiversity and Land Planning, CIBIO, Vairão, Portugal

[27]Departamento de Zooloxía, Xenética e Antropoloxía Física, Universidade de Santiago de Compostela, Santiago de Compostela, Spain

Grant D. Lindley and Chris J. Jolly should be considered joint first authors.

[28]Centre for Integrative Ecology, School of Life and Environmental Sciences, Deakin University, Burwood, Victoria, Australia

[29]INRAE, URFM, Avignon, France

[30]School of Natural Sciences, University of Tasmania, Hobart, Tasmania, Australia

Correspondence
Dale G. Nimmo, The Gulbali Institute, School of Agricultural, Environmental and Veterinary Sciences, Charles Sturt University, Albury, NSW 2640, Australia.
Email: dnimmo@csu.edu.au

Funding information
Threatened Species Recovery Hub; NSW Bushfire Risk Management Research Hub; Australian Wildlife Society; World Wildlife Fund

Handling Editor: Benjamin Poulter

Abstract

Background: 'Megafire' is an emerging concept commonly used to describe fires that are extreme in terms of size, behaviour, and/or impacts, but the term's meaning remains ambiguous.

Approach: We sought to resolve ambiguity surrounding the meaning of 'megafire' by conducting a structured review of the use and definition of the term in several languages in the peer-reviewed scientific literature. We collated definitions and descriptions of megafire and identified criteria frequently invoked to define megafire. We recorded the size and location of megafires and mapped them to reveal global variation in the size of fires described as megafires.

Results: We identified 109 studies that define the term 'megafire' or identify a megafire, with the term first appearing in the peer-reviewed literature in 2005. Seventy-one (~65%) of these studies attempted to describe or define the term. There was considerable variability in the criteria used to define megafire, although definitions of megafire based on fire size were most common. Megafire size thresholds varied geographically from > 100–100,000 ha, with fires > 10,000 ha the most common size threshold (41%, 18/44 studies). Definitions of megafire were most common from studies led by authors from North America (52%, 37/71). We recorded 137 instances from 84 studies where fires were reported as megafires, the vast majority (94%, 129/137) of which exceed 10,000 ha in size. Megafires occurred in a range of biomes, but were most frequently described in forested biomes (112/137, 82%), and usually described single ignition fires (59% 81/137).

Conclusion: As Earth's climate and ecosystems change, it is important that scientists can communicate trends in the occurrence of larger and more extreme fires with clarity. To overcome ambiguity, we suggest a definition of megafire as fires > 10,000 ha arising from single or multiple related ignition events. We introduce two additional terms – gigafire (> 100,000 ha) and terafire (> 1,000,000 ha) – for fires of an even larger scale than megafires.

KEYWORDS
Anthropocene, catastrophic fire, climate change, extreme wildfire event, mega-fire, Pyrocene, wildfire disaster

1 | INTRODUCTION

Fire has shaped life on Earth for hundreds of millions of years, modifying ecosystems (Pausas & Keeley, 2021), affecting evolutionary processes (Nimmo et al., 2021; Pausas & Parr, 2018), and altering species distributions (Archibald et al., 2018; He et al., 2019). Although humans have long influenced fire regimes (Bowman et al., 2011; Ellis et al., 2021), recent human-induced change is rapidly altering fire activity across the globe (Andela et al., 2017; Bowman et al., 2020). Climatic change (Abatzoglou & Williams, 2016; Jolly et al., 2015), coupled with landscape modification (Cochrane, 2003), the displacement of Indigenous peoples (Fletcher, Hamilton, et al., 2021; Fletcher, Romano, et al., 2021), and the introduction of new species (Fusco et al., 2019), have altered fire regimes across the world, imperilling species and ecosystems (Kelly et al., 2020). Projections suggest an increase in global fire activity across vast portions of the

Earth's surface in the coming decades (IPCC, 2021; United Nations Environment Programme, 2022; Wu et al., 2021).

At the centre of observed changes in global fire activity has been the apparent rise of the 'megafire'. But what, exactly, is a megafire? Despite early adopters of the term providing relatively clear definitions (Williams et al., 2005), a cursory search of the literature finds that the concept has evolved, such that Tedim et al. (2018) note 'disagreement over the parameters used to define megafire makes this term a problematic one'. 'Megafire' is now used to describe a variety of fire scenarios, from spatially and temporally discrete fire events (e.g., Keeley & Zedler, 2009), to groups of fires that are clustered in space and time (e.g., Walker et al., 2018), to the sum of fire activity over an entire fire season (e.g., Lapere et al., 2021). Megafires are defined by various parameters – individually and in combination – including fire size (Godfree et al., 2021), behaviour (French et al., 2016), resistance to containment (Tedim et al., 2015), and socio-economic or environmental outcomes (Groisman et al., 2017).

Linguistic uncertainty pervades many areas of science (Johnson & Lidström, 2018), and includes vagueness (the inability of a concept to categorize borderline cases); ambiguity (terms having multiple meanings); context dependency (a lack of context that would allow meaning to be understood); and indeterminacy (unforeseen ambiguity arising through changes in meaning over time) (Regan et al., 2002). Megafire suffers from all of these uncertainties. Yet, as the world warms and fire regimes become increasingly novel, a standard terminology for descriptors of fire is critical. In the context of changing fire regimes, the unstandardized use of the term 'megafire' could contribute to mismatches between perceptions and reality of trends in fire activity. For example, Doerr and Santín (2016) contrast the widespread perception of increasing fire activity with empirical data that, at the time of publication, demonstrated an overall decrease in fire at both global and some regional scales. Such misconceptions can have real-world consequences, such as investment in policies (e.g., fire suppression) that are not supported by place-based evidence (Doerr & Santín, 2016). A consistent and clear terminology describing megafires could help to reduce misconceptions about the ecological role of large fires, while aiding in understanding their drivers, trends and impacts, from regional to global scales.

One approach to tackling linguistic uncertainty is to provide clearer definitions while making conscious decisions about the term's future usage (Regan et al., 2002). Resolving the linguistic ambiguity surrounding the term 'megafire' would allow clearer communication between scientists and the general public, but it is important that any revised definition is reconcilable with past usage (Regan et al., 2002). To this end, we review the use of the term 'megafire' in several languages in the peer-reviewed scientific literature, identify key criteria used to define megafire, and record the size of fires described as megafires around the world. We also consider related concepts (e.g., 'extreme wildfire event') to help assess gaps in the terminology surrounding extremely large fires and their impacts. After identifying clear foci of megafire definitions, we propose a terminological standardization, which involves additional terms to provide further granularity and consistency to the study of large fires globally. It is our hope that removing linguistic uncertainty of 'megafire' will result in more rigorous use of the term amongst scientists, while also clarifying its use in communications between scientists, policy makers, and the broader public.

2 | METHODS

2.1 | Structured review of the peer-reviewed scientific literature

We conducted a structured review of the peer-reviewed scientific literature to investigate the use of the term 'megafire' and how it has been defined. We considered a study appropriate for inclusion when an explicit definition was supplied for the term 'megafire', or when a study simply referred to the occurrence of a 'megafire' in any part of the study. Given that our focus was specifically on megafire, studies that referenced other terms for large fires (e.g., 'very large fire', 'catastrophic fire' or 'extreme wildfire') were not included. Our search database included field studies, modelling studies and reviews referring to the term 'megafire'. We recognize that our focus on the use of the term 'megafire' by scientists in the peer-reviewed literature means that the term's use in other areas (e.g., media, social media, policy discussions, policy documents, laws) is overlooked. However, our objective is to understand how megafire is used in a scientific context, and thus we limit the scope of our review to the peer-reviewed scientific literature.

We searched Scopus and Web of Science in January 2022 (English, French, Italian, Portuguese and Spanish) for combinations of search terms involving 'megafire*/mégafeu*/megaincendi*/megafogo*', 'mega-fire*/mega-incendi*/mega-fogo*', 'mega' and/or 'fire/incendi*/fogo*' (Appendices S1 and S2). These terms also cover other Iberian languages, such as Catalan and Galician. Ignoring non-English language studies can introduce bias into syntheses (Trisos et al., 2021). We detected and collected additional mentions of 'megafire' from peer-reviewed scientific literature published during our search period via Google Scholar alerts. We attempted to replicate this search for a Chinese translation or equivalent of 'megafire' in Scopus, Web of Science and the China National Knowledge Infrastructure (CNKI); however, no Chinese equivalent of 'megafire' could be identified (Appendix S1). The closest Chinese equivalent was 特别重大森林火灾, 'specially heavy forest fire', which refers to fires that either affect > 1,000 ha of forest, or that cause > 30 deaths or > 100 serious injuries (General Office of the State Council, 2018).

Our database searches returned 556 unique results, with an additional seven studies found via Google Scholar alerts, giving a total of 563 studies (English: n = 557; Portuguese: n = 2; and Spanish: n = 4). We then screened results by reading the title and abstracts, removing studies that failed to meet our inclusion criteria, retaining 247 studies that were appropriate for full-text review (Appendix S2). From this, 109 studies mentioned 'megafire' and were appropriate for analysis (English: n = 106; Portuguese: n = 1; Spanish: n = 2). Studies were excluded if they neither defined the term megafire, nor described the occurrence of a megafire. Of these 109 studies, 71 studies defined or described the term ‘megafire’ and 84 studies referenced the occurrence of 137 megafire events. The search located definitions from 12 scientific fields, with ecology (70%; 50/71), biogeography (7%; 5/71), economics (4%; 3/71) and meteorology (4%; 3/71) most well represented.

2.2 | What defines a ‘megafire’?

After reviewing the 71 studies that define or describe the term ‘megafire’, we created a checklist of criteria used to define or describe ‘megafire’ (Table 1). In some cases, studies that used the term did not explicitly define it. For instance, Keeley and Zedler (2009) refer to a series of megafires ~50,000 ha or larger, but do not state explicitly that 50,000 ha is a size threshold for megafires. By contrast, Whitney et al. (2015) refer to megafires as ‘wildfires >100 km^2’, providing an explicit statement of the size threshold to be considered a megafire. For the collation of definitions, we only included studies that explicitly stated the defining characteristics of megafire. The criteria included in each definition were then recorded. The ‘location’ of each megafire definition was defined by the first author’s primary affiliation.

For the 84 studies that made reference to specific megafires, we recorded the fire location and the size/area of the fire being referred to as a megafire. Based on the location of each ‘megafire’ event reported in the literature, we assigned them to a broad terrestrial biome following Olson et al. (2001). Megafires were also categorized according to whether they constituted: (a) a single, discrete fire event from a specific ignition source (i.e., ‘single ignition fires’); (b) multiple fire events that were clustered in space and time and typically arose from a common ignition source, whilst having different ignition points (‘multiple ignition fires’); or (c) multiple fire events that arose from separate ignition sources, and were typically spatially or temporally discontinuous (‘separate ignition fires’), for instance, the sum of all fire activity across a large geographic area over an entire fire season. Given that some studies reported on many megafires, we also recorded the smallest megafire recorded in each study to avoid any single study (and hence interpretation of what constitutes a megafire) overshadowing broader trends. The smallest fire was used because this represents the lower size limit of what the authors regard as a megafire in each study.

3 | RESULTS

‘Megafire’ appeared in the peer-reviewed scientific literature as early as 2005, described in relation to fire management policy in the United States as ‘The largest fires, classified as “megafires” by public agencies’ (Stephens & Ruth, 2005). The concept has since been used increasingly to describe fires across the globe (Figure 1). The term ‘megafire’ was initially used to describe fires that were so large and complex, and so extreme in their behaviour, that they required different approaches to suppression compared to other large fires (Williams et al., 2005). We identified seven criteria that are regularly invoked to define ‘megafire’ (Table 1) and categorized them as being attribute-oriented (i.e., fire size, behaviour, resistance to control, novelty) or impact-oriented (i.e., fire severity, socio-economic costs, environmental effects, and human fatalities) (see Table 2 for examples). In total, 96% (68/71 studies) of definitions included at least one attribute-oriented criterion, 32% (23/71) included at least one impact-oriented criterion, and 28% (20/71) included at least one of both. A total of 68% (48/71) of studies defined megafires by attribute-oriented criteria only, whereas 4% (3/71) were defined only by impact-oriented criteria.

The most common criterion used to define megafire was fire size (i.e., area burned), mentioned in 85% (60/71) of definitions, with 35% (25/71) of studies defining megafire by size alone (Figure 2). The remaining 65% of studies that defined megafire by fire size in combination with at least one other criterion, did so using combinations of all seven other criteria (Table 1). Environmental impacts of megafire were referred to in combination with fire size most often (23%, 14/60), and human impacts least often (10%, 6/60). Hence, there is substantial variability regarding other criteria that, when combined with fire size, were used to define megafire. The next most common criterion after fire size was socio-economic impacts, referred to in 28% (20/71) of definitions, followed by fire behaviour and environmental impacts, which were each referred to in 23% (16/71)

TABLE 1 Criteria used to define or describe megafires throughout the published literature

Criteria	Description
Fire size or burnt area	Reference to the size of a fire event or total area burned, either qualitatively (i.e., ‘large’) or quantitatively (e.g., > 10,000 ha)
Fire behaviour	Reference to high fire intensity or extreme fire behaviour (e.g., fast rate of spread)
Resistance to control	Reference to the incapacity to control or suppress fire, or the need for new approaches to do so
Novelty	Reference to fire deviating from the historical range of fire activity for a given ecosystem, typically in relation to fire size or behaviour
Fire severity	Reference to high severity fire
Socio-economic impacts	Reference to social or economic impacts of fire
Environmental impacts	Reference to environmental or ecological impacts of fire
Human impacts	Reference to loss of human life or assets from fire

FIGURE 1 The number of studies that defined, described or reported a 'megafire' found during a structured review of the peer-reviewed scientific literature. Continent was assigned as that of the first author's primary affiliation. Note: at the time of this review 2022 was incomplete (denoted by an asterisk)

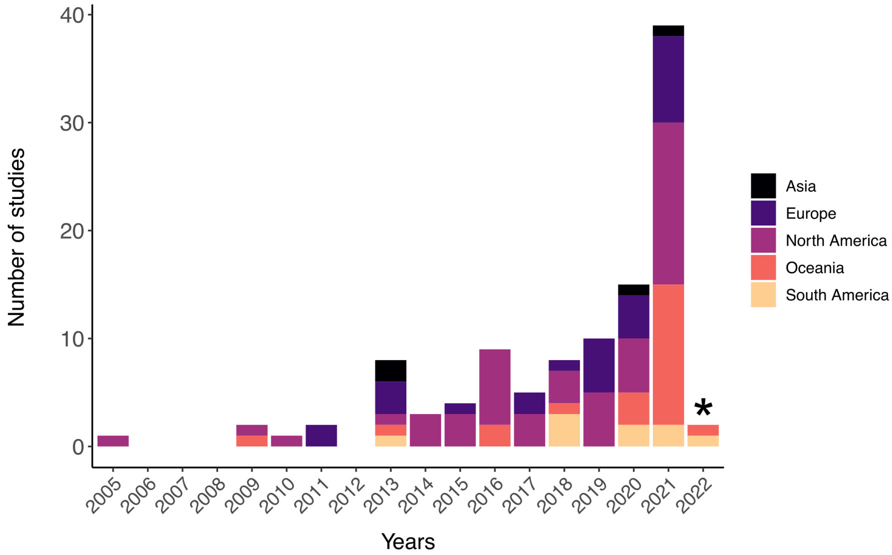

TABLE 2 Examples of how megafire has been defined or described throughout the published literature, and the criteria in which we categorized these definitions into

Reference	Type	Description
Alló and Loureiro (2020)	Fire size, fire behaviour, novelty	'A megafire is defined as a wildfire that shows a behavior outside the capacity of the extinction system, either because of the high flame lengths, high speed of propagation, or because of the presence of canopy fire activity. According to official statistics, a megafire contains a burned surface area greater than 500 ha of forest.'
Diakakis et al. (2017)	Resistance to control, socio-economic impacts	'Mega-fires expand during extremely dry, hot and windy weather conditions and are fuelled by dense vegetation and unmanaged forest fuels (Williams et al., 2011). Most of the time mega-fires overwhelm the most advanced fire fighting systems and organizations with consequences reaching beyond damages to property and infrastructure requiring a large commitment of financial and other resources (Omi, 2005).'
French et al. (2016)	Fire size, fire behaviour	'We describe this fire as a megafire because of both the area burnt and its severity.'
Godfree et al. (2021)	Fire size	'Most megafires (here defined as >0.1 Mha) arose following the merging of multiple, independent large fires.'
Groisman et al. (2017)	Socio-economic impacts, environmental impacts, human impacts	'A typical feature of the current fire regime is increasing frequency and severity of mega-fires, defined as fires that involve high suppression costs, property losses, natural resource damages, and loss of life (Williams, 2013).'
Pausas and Keeley (2021)	Fire size, novelty	'Wildfires at the extreme of the frequency size distribution for a given ecosystem, typically megafires are outliers (in a statistical sense) in relation to the historical fire size distribution. They are often driven by strong winds and/or high and continuous fuel loads (i.e. wind-driven or fuel-driven wildfires).'
Schofield et al. (2020)	Fire size, fire behaviour	'Including so-called "megafires" that burn >10,000 ha at high severity (Stephens et al., 2014).'
Tedim et al. (2015)	Resistance to control	'Mega-fires exceed all efforts at direct control even in the best prepared regions of the world (Bartlett et al., 2007; Ozturk et al., 2010; Stephens & Ruth, 2005; Williams, 2010).'

of definitions. Studies that did not consider fire size as a criterion for megafire (15%, 11/71) tended to consider socio-economic impacts (64%, 7/11) and resistance to control (64%, 7/11) as defining features. Authors from South America were more likely to consider impacts in their definition of megafire, particularly socio-economic impacts (Figure 2), whereas authors from Oceania were proportionately more likely to include fire severity in their definition (Figure 2).

Of the studies that used size to define megafire, 73% (44/60) identified a specific size threshold, whereas the remaining studies made a more general reference to fire size or burnt area (e.g.,

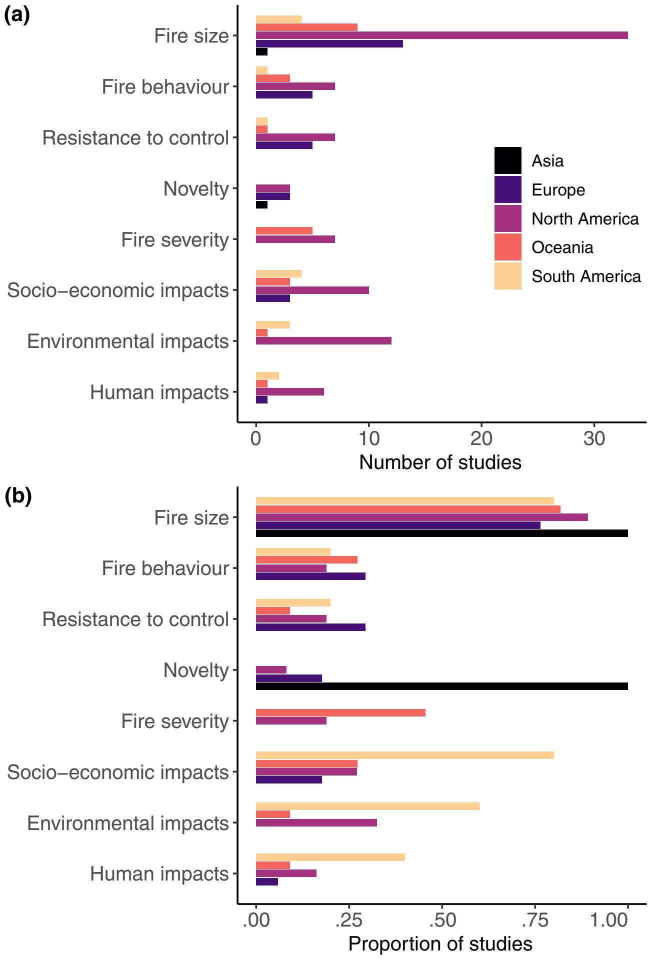

FIGURE 2 The number (a) and proportion (b) of definitions or descriptions of megafire that invoke various criteria

'a very large burnt area'; Maditinos & Vassiliadis, 2011). Of those studies that specified size thresholds for megafires, the most commonly used threshold was ≥ 10,000 ha (41%, 18/44) (Figure 3). The second most commonly specified size thresholds were in the 10,001–50,000 ha range (Figure 3), specified in 32% (14/44) of definitions (e.g., Anthony et al., 2021; Barton & Poulos, 2019; Maezumi et al., 2018). The lowest thresholds identified were 100 ha (Fidelis et al., 2018) and 500 ha (Alló & Loureiro, 2020; Mancini et al., 2017). When European authors provided a size threshold, it was typically smaller than that proposed by authors from North America and Oceania (Figure 3). Some studies defined megafires statistically relative to a region-specific baseline (e.g., Pausas & Keeley, 2021; Santos et al., 2022). For instance, Khorshidi et al. (2020) defined megafires as those > 27,000 ha, corresponding to the 99.98th percentile of fire size in the study region.

Definitions of megafire were provided in studies led by authors from five continents but were most often defined in studies led by authors from North America (52%, 37/71) and Europe (24%, 17/71) (Figure 3). There appears to be geographic variation in the criteria used to define megafire (Figure 2), with studies led by North American authors more likely to include fire size in their definition than European authors (Figure 2). When European authors did include fire size in their definition of megafire, they were less likely to provide a quantitative size or area threshold (Figures 2 and 3).

When defining megafire, 76% (54/71) of authors referred to a previous definition, sometimes outside of the peer-reviewed scientific literature. The most commonly cited study was Stephens et al. (2014), which was referred to in 28% (20/71) of instances, followed by Williams (2013), referred to in 8% (6/71) of instances. Of the studies that cited Stephens et al. (2014) when defining megafire, 80% (16/20) used fire size to define megafire and 65% (13/20) identified 10,000 ha as the minimum size threshold. By contrast, only one study that cited Stephens et al. (2014) identified 'resistance to control' as a defining feature of megafire (Smith et al., 2016), and one other included socio-economic impacts in their definition (Jung, 2020). Hence, Stephens et al. (2014) is used often to argue for a strict, area-based definition of megafire (i.e., fires that burn > 10,000 ha), even though that work provides a far more expansive definition of megafire, including consideration of novelty, socio-economic impacts, and human impacts, as well as size.

We recorded 137 instances from 84 studies where fires were reported as megafires in the literature (Figure 4). These reported megafires varied in size by many orders of magnitude, from 1,042 ha (Gutiérrez et al., 2020) to 18,983,588 ha (Lee et al., 2021), but were predominantly either 10,001–100,000 ha (34%, 46/137) or 100,001–1,000,000 ha (47%, 64/137) (Figure 4). Overall, 94% (129/137) of fires described as 'megafires' exceeded the 10,000-ha size threshold, leaving 6% of fires below the threshold (8/137) (Figure 4). There was a strong geographic bias in the distribution of reported megafires; over half occurred (56%, 77/137) in North America, with a particular concentration of megafires being described on the east coast of the United States, and one sixth in Europe (17%, 23/137) (Figure 4, Appendix S3). Most (82%, 112/137) megafires reported in the literature burned forested biomes (Appendix S4); however, megafires were also reported from grassland, shrubland and savanna biomes (18%, 25/137; Appendix S4). Megafire was most often used to describe single ignition fires (59%, 81/137; Appendix S5), but was also used to describe multiple ignition fires (21%, 29/137) and separate ignition fires (20%, 27/137) (Appendix S5).

4 | DISCUSSION

Our review has shown that megafire is a multifaceted concept with definitions encompassing a broad range of criteria, from the attributes of fire events to their socio-economic and environmental impacts. Attribute-oriented definitions, such as fire size and behaviour, predominate. While initially framed as a concept centred on fires that were abnormally difficult to suppress (Stephens & Ruth, 2005), the megafire concept has been applied inconsistently in the scientific literature. Megafire has often been described as a spatial concept, frequently with reference to specific size thresholds, but with variability across the literature regarding what those thresholds should

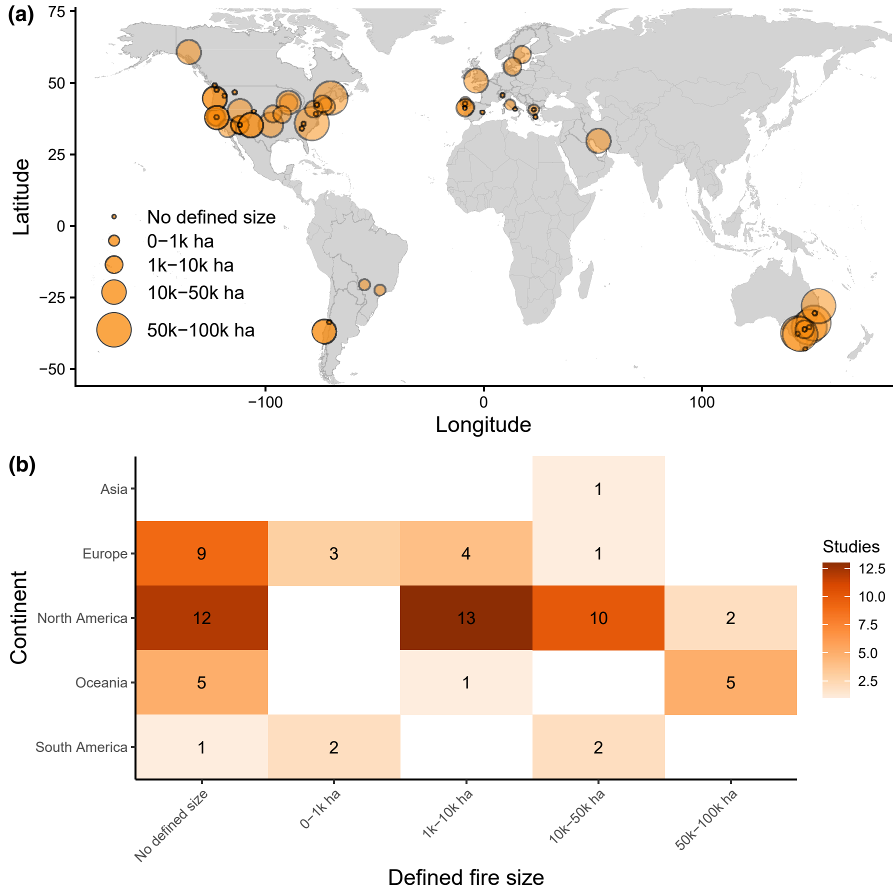

FIGURE 3 (a) Map of published megafire definitions, the minimum size threshold specific in the definition, and the location of their first author's primary affiliation; and (b) the number of studies that define megafire within various minimum size categories, and how this varies according to the lead author's geographic location. Specific minimum size ranges were: no defined size, 0–1,000, 1,001–10,000, 10,001–50,000 and 50,001–100,000 ha

be. Megafire is commonly used to describe fires in forest biomes arising from a single ignition source, or multiple ignition sources that are related, and occasionally to describe fires in non-forest ecosystems (e.g., grasslands, savannas) and extreme fire seasons arising from unrelated ignitions (sensu Duane et al., 2021). Clearly, megafire is currently being used to describe a considerable range of fire activity.

4.1 | Defining megafire

What makes for a useful scientific definition? In our view, scientific definitions should be unambiguous and allow for standardized and repeatable measurement, and hence also, direct comparisons of studies, including meta-analyses. Further, scientific terminology should seek to avoid redundancy by using multiple terms describing the same phenomena (Driscoll et al., 2019; Pulsford et al., 2016). Instead, related terms should complement one another, allowing for complex phenomena to be described by combinations of non-overlapping concepts. Therefore, before answering 'what is a megafire?', it is worth considering terms with existing definitions that relate closely, and at times, overlap with some megafire definitions.

Tedim et al. (2018) use the term 'wildfire disaster' to describe fires based on their socio-economic and ecological impacts, otherwise referred to as 'catastrophic fires'. 'Disaster' – an event that causes great damage – makes it clear that *wildfire disasters* are defined by their impacts, not their inherent characteristics. *Wildfire disasters* can be small or large in size, and occur due to fire behaviour and/or inadequate planning and protection (Tedim et al., 2018). Therefore, *wildfire disaster* captures the criterion of resistance to control and impact-oriented definitions of megafire. We would add that *wildfire disasters* should encapsulate other forms of damage, such as harm done to the values of local and Indigenous peoples, which can have profound individual and cultural impacts.

Another recently defined and related term is 'extreme wildfire events' (Duane et al., 2021; Tedim et al., 2018). *Extreme wildfire events* are defined as 'a pyro-convective phenomenon overwhelming capacity of control (fireline intensity currently assumed ≥10,000 kW m^{-1}; rate of spread >50 m/min), exhibiting spotting distance >1 km, and erratic and unpredictable fire behavior and spread' (Tedim et al., 2018). Thus, although *extreme wildfire events* are often large, they are characterized by their fire behaviour and resistance to control, not by their size (Tedim et al., 2018). Duane et al. (2021) classified several relatively small fires as extreme wildfire events (e.g., Greece's Attica fire, which burned 1,276 ha in 2018). Bowman et al. (2017) note that *extreme wildfire events* can be *wildfire disasters*, but that there are many instances in which they are not. For example, when *extreme wildfire events* burn in remote areas with low population density. When combined with the concept of *wildfire disaster*, *extreme wildfire events* describe fires – small or large – that exhibit extreme behaviour and may result in substantial socio-economic and human costs (Bowman et al., 2017).

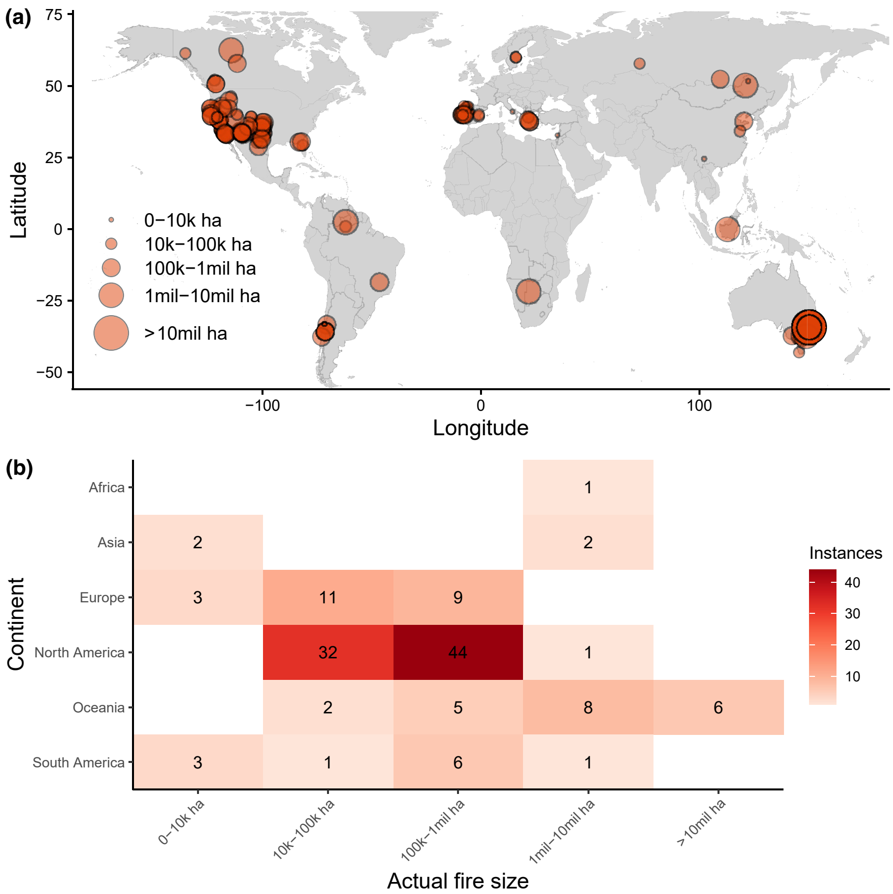

FIGURE 4 (a) Map of reported megafires and their corresponding size and location as reported in the literature; and (b) number of instances where studies mention a megafire event, provide its size and the corresponding continent. Size ranges used were 0–10,000, 10,001–100,000, 100,001–1,000,000, 1,000,001–10,000,000 and > 10,000,000 ha

What remains undescribed by both *wildfire disaster* and *extreme wildfire event* is the spatial component of fires (i.e., fire size). Other terms do exist that capture the spatial components of fire: these include *large fire*, *very large fires* and *extremely large fires*. However, like 'megafire', these terms lack consistent definitions (Tedim et al., 2018). Despite fire size not being a defining feature in early definitions of megafire (Williams, 2013), there is now a broad perception across the literature that megafires are defined by their size, particularly when the concept is operationalized (e.g., to track drivers and trends in megafires; Keeley & Zedler, 2009). Further, there has been widespread adoption of a size threshold, that of > 10,000 ha, particularly amongst scientists based in North America, and the vast majority of fires described as megafire in the literature (94%) exceed this minimum size threshold.

4.2 | Megafire: moving forward

Given the concepts outlined above, megafire could fill a terminological gap in fire science by being a purely spatial concept, complementing existing terms such as *wildfire disaster* and *extreme fire events*. In many instances, megafire appears already to be filling that gap, given the widespread adoption of size thresholds. Specific size thresholds, such as > 10,000 ha, offer a clear and absolute measure of fire size that can be applied across the world. As stated earlier, for scientific definitions to be useful, they should be unambiguous, measurable and repeatable. Therefore, based on our review, we suggest megafire be defined as:

> Spatially and temporally continuous fire arising from single ignition or multiple related ignition events that exceed 10,000 ha in area.

For context, 10,000 ha is approximately 40% bigger than Manhattan or ~14,000 football/soccer fields. The 10,000-ha threshold is the most widely used threshold in definitions of megafire, capturing > 90% of described megafires. It is therefore consistent with current usage, an important consideration when clarifying definitions to resolve linguistic uncertainty (Regan et al., 2002). This definition excludes multiple fires that are spatially and temporally discontinuous and arise from separate ignitions, such as the sum of fire activity across a defined area over an entire fire season. Duane et al. (2021) refer to these as '*extreme fire seasons*'. The proposed definition of megafire does not capture the complexity of some existing definitions, but is scientifically precise and measurable, and complementary to other fire concepts that capture some of the criteria omitted in this definition (i.e., fire behaviour, socio-economic and environmental impacts, see Conclusions). The simplicity of the definition reduces the amount and type of data needed to identify megafires. If adopted further, it could facilitate clearer communication amongst scientists, and between scientists, policy makers, and the broader public.

Given that the definition above refers only to fire size and ignition, megafires according to this definition can occur in a range of biomes, including forests, grasslands, savannas and deserts. This classification will allow researchers to identify trends in the occurrence of megafire at regional, continental, or global scales, the prevalence of megafire in different ecosystem types, the drivers of megafire occurrence, their social and economic impacts, and to synthesize with greater ease the ecological effects of megafire. This definition will mean that megafires are unlikely to occur in some places, which is similar to other abiotic disturbances that are specific to, or more prevalent in, particular regions of the globe, such as cyclones and earthquakes. We offer an alternative conceptual framework for a more context-specific measure of extreme fire below. Although our definition includes a discrete size threshold (i.e., 10,000 ha), approaches to modelling megafire occurrence could soften this threshold by applying, for instance, fuzzy set theory to model the degree of membership of any given fire in our 'megafire' category (Regan et al., 2002). We also acknowledge that there is value in documenting and modelling exact fire sizes (i.e., as opposed to fire size categories) and their distributions over space and time, and we encourage fire scientists to continue to do so in future work. 'Megafire' is intended to add to, not replace, detailed and nuanced analyses of trends in fire size.

While a useful starting point, there is substantial variability in fire size beyond this threshold, therefore requiring further granularity in fire size categories. Fires > 100,000 or > 1,000,000 ha are not unprecedented (Duane et al., 2021), and likely have distinct social and ecological impacts. The trends, patterns, drivers and impacts of fires in these size categories might also be distinct.

Fires in the western United States that exceed perceived size thresholds of 'megafire' are already being described by the term 'gigafire', initially in popular media and, more recently, in the peer-reviewed scientific literature (Langpap & Wu, 2021; Zhuang et al., 2021). This term is potentially useful in describing fires far larger than the minimum size threshold for megafires, but with an important caveat. The use of 'mega' and 'giga' alike in describing fires must be in relation to the Ancient Greek etymology of these prefixes, where 'mega' means 'large' and 'giga' means 'giant', as opposed to their use in the International System of Units (ISU) system (i.e., mega = 10^6, giga = 10^9). Such numerical classifications span a far greater range of sizes than fire when measured by standard units of area used to describe fire (e.g., ha or km^2), and so the ISU framework cannot be applied to characterize fire size in a meaningful way.

With this in mind, gigafire, or 'giant fire', could be used to characterize fires an order of magnitude greater than the minimum size threshold for megafires (i.e., fires of > 100,000 ha in area, equivalent in size to ~140,000 football/soccer fields; Table 3). Following this logic, it would be possible also to define an even larger fire size category, an order of magnitude larger than the minimum size threshold for gigafire, as 'terafire' (derived from the Ancient Greek term 'tera' that translates to 'monster'; i.e., fires of > 1,000,000 ha in area, equivalent in size to ~1.4 million football/soccer fields; Table 3).

The size threshold of 100,000 ha for gigafire corresponds with, and we suggest replaces, some existing definitions of megafires (e.g., Adams, 2013), and many fires currently described as megafires would also be defined as gigafires under this definition (Figure 4). For instance, many of Australia's 2019–2020 'megafires' would fall under the gigafire concept as described. We know of no other term for fires > 1,000,000 ha, but fires of such size do occur (Duane et al., 2021); for instance, in 2016, a wildfire in the Kimberley region of Western Australia burned > 1.2 M ha. The mega, giga, tera hierarchy, although not aligned to the ISU

TABLE 3 Definitions of terms used to describe large and novel fires

Term	Definition
Extreme wildfire event	A pyro-convective phenomenon overwhelming capacity of control (fireline intensity currently assumed ≥ 10,000 kW/m; rate of spread > 50 m/min), exhibiting spotting distance > 1 km, and erratic and unpredictable fire behaviour and spread. It represents a heightened threat to crews, population, assets, and natural values, and likely causes relevant negative socio-economic and environmental impacts (Tedim et al., 2018).
Wildfire disaster	Wildfires that have at least one of the following criteria: (a) cause human casualties (either firefighters or civilians), (b) consume people's primary residences, and (c) are declared 'disasters' by governments (Bowman et al., 2017).
Environmentally extreme fire	A fire event (single ignition or multiple, related ignitions) that is extreme in at least one dimension (e.g., size, intensity, severity) relative to a historic baseline. Environmentally extreme wildfires are extreme events (Katz et al., 2005), and their extremity can be estimated using extreme value theory (e.g., a 1/100-year event, Gaines & Denny, 1993).
Extreme wildfire season	Fire seasons in which the burnt area is extreme relative to a historic baseline (Duane et al., 2021). Extreme wildfire seasons are often the result of numerous, unrelated ignitions.
特别重大森林火灾 (specially heavy forest fire)	Fires that affect > 1,000 ha of forest, result in > 30 human fatalities, or result in serious injury to > 100 people (General Office of the State Council, 2018).
Megafire	Spatially and temporally continuous fire arising from single ignition or multiple related ignition events that exceed 10,000 ha in area.
Gigafire	Spatially and temporally continuous fire arising from single ignition or multiple related ignition events that exceed 100,000 ha in area.
Terafire	Spatially and temporally continuous fire arising from single ignition or multiple related ignition events that exceed 1,000,000 ha in area.

system in this instance, provides a familiar language for increasing size-based thresholds. Given unprecedented fires in recent years that have burned areas far in excess of 10,000 ha (e.g., Boer et al., 2020; Keeley & Syphard, 2021; Mack et al., 2011), and the projected increase in extreme fire weather (IPCC, 2021; United Nations Environment Programme, 2022), the use of these terms may become increasingly necessary to describe fires in the coming decades.

4.3 | Environmentally extreme fire

The definition of megafire offered above fails to encapsulate the context dependence of fire size and behaviour that is captured in some previous descriptions (e.g., Khorshidi et al., 2020). What constitutes a 'large' fire in one ecosystem may not apply to others, as it depends on the historical variability of fire size (Pausas & Keeley, 2021). Hence, a remaining challenge for the characterization of fire is to identify common thresholds for what constitutes environmentally extreme fire. We suggest that this concept of extreme fire, relative to a specific context or baseline, is best captured within the broader concept of 'ecological extremes' (e.g., Gaines & Denny, 1993; Katz et al., 2005). Extreme ecological events are rare – but not always unprecedented – events that play a disproportionate role in ecosystems (Gutschick & BassiriRad, 2003). 'Extremity' can be measured in terms of the interval between events of a given magnitude in relation to the historical frequency distribution (e.g., a 1/100-year event; Gutschick & BassiriRad, 2003). Extreme value theory can be applied to fire size (Moritz, 1997), but can also be applied to other measures of fire, such as fire intensity or the extent of areas burnt at high severity (Keyser & Westerling, 2019). However, because extreme events are extreme only in relation to a 'baseline', they will be sensitive to shifts in baselines that are known to occur in fire regimes. For instance, burning by Martu in Australia's western deserts decouples the relationship between climate and fire, such that large fires are less likely to occur in areas subject to frequent Martu burning, even when climatic conditions favour them (Bliege Bird et al., 2012). What constitutes an 'extreme fire event' under Martu stewardship may fit within the norm of fire activity in the absence of Martu burning.

The complementarity of the definitions offered here and elsewhere is considerable (Table 3). Under a spatial definition, megafires can be *extreme wildfire events*, *extreme ecological events*, and *wildfire disasters*, but they are not *necessarily* any of these. Megafires are more likely to be *wildfire disasters* when they are *extreme wildfire events* occurring in densely populated areas. By contrast, megafires could burn under benign conditions in remote areas, without triggering the loss of life or property, but exceeding the thresholds for being defined as a megafire. Megafires are more likely to be *extreme ecological events* in ecosystems that historically do not experience large fires or have altered or interrupted fire regimes, whereas they may be a normal occurrence in others.

5 | CONCLUSIONS

As Earth's climate shifts, and the risk of larger and more extreme fire events increases in some locations, it is important that scientists are able to communicate trends in the occurrence of such fires without ambiguity. Ensuring that scientific terminology appropriately and consistently describes fire events is one way of promoting clear communication within the scientific community and beyond (Tedim et al., 2018). We have provided a rationale for one approach for achieving this, but we recognize that not everyone will agree with our chosen terminology and we welcome debate on the issue. While our structured review of 'megafire' incorporated scientific literature in three languages, our review does not explicitly examine perspectives beyond the scientific community. Importantly, the scientific literature is biased towards particular voices, and away from others (e.g., local and Indigenous perspectives; see Fletcher, Hamilton, et al., 2021; Fletcher, Romano, et al., 2021; Nuñez et al., 2021), and our review of the scientific literature undoubtably carries these biases. We therefore invite dialogue that can enhance the diversity of perspectives regarding the characterization of fire, resulting in clearer, more measurable, and repeatable descriptions of large fires across the globe.

ACKNOWLEDGMENTS

We thank the World Wildlife Fund and Australian Wildlife Society for supporting GDL's research, and the National Environmental Science Program's Threatened Species Recovery Hub (CJJ, DGN) and the Australian Research Council (DGN; DE170101466). RHN and GJW are funded by NSW Department of Planning, Industries and Environment through the NSW Bushfire Risk Management Research Hub. AR is supported by the Spanish Ministry of Science and Innovation (IJC2019-041033-I) and the Portuguese national funds through FCT Foundation for Science and Technology, I.P., under the FirESmart project (PCIF/MOG/0083/2017).

AUTHOR CONTRIBUTIONS

GDL and CJJ contributed equally to this paper and should be considered joint first authors. GDL, CJJ and DGN conceived the study. GDL, CKFL, QW, AR and JR conducted the structured review. GDL, CJJ, DGN, TSD, WLG, CKFL, QW, AR and JR discussed and interpreted the data. GDL, CJJ, WLG and DGN curated, analysed and visualised the data. GDL, CJJ and DGN led the writing and revision of the manuscript with contribution from all authors.

DATA AVAILABILITY STATEMENT

A list of the references from which the data were extracted can be found in the Appendix A: Data sources. The data used in this study are openly available at zenodo.org: https://doi.org/10.5281/zenodo.6252145.

ORCID

Grant D. Linley https://orcid.org/0000-0003-3512-2748
Chris J. Jolly https://orcid.org/0000-0002-5234-0897

Tim S. Doherty https://orcid.org/0000-0001-7745-0251
William L. Geary https://orcid.org/0000-0002-6520-689X
Dolors Armenteras https://orcid.org/0000-0003-0922-7298
Claire M. Belcher https://orcid.org/0000-0003-3496-8290
Andrea Duane https://orcid.org/0000-0001-7687-4546
Michael-Shawn Fletcher https://orcid.org/0000-0002-1854-5629
Melisa A. Giorgis https://orcid.org/0000-0001-6126-6660
Angie Haslem https://orcid.org/0000-0002-2849-9486
Gavin M. Jones https://orcid.org/0000-0002-5102-1229
Luke T. Kelly https://orcid.org/0000-0002-3127-3111
Calvin K. F. Lee https://orcid.org/0000-0001-8277-8614
Rachael H. Nolan https://orcid.org/0000-0001-9277-5142
Catherine L. Parr https://orcid.org/0000-0003-1627-763X
Juli G. Pausas https://orcid.org/0000-0003-3533-5786
Jodi N. Price https://orcid.org/0000-0003-2899-7693
Adrián Regos https://orcid.org/0000-0003-1983-936X
Euan G. Ritchie https://orcid.org/0000-0003-4410-8868
Julien Ruffault https://orcid.org/0000-0003-3647-8172
Grant J. Williamson https://orcid.org/0000-0002-3469-7550
Qianhan Wu https://orcid.org/0000-0002-7557-8152
Dale G. Nimmo https://orcid.org/0000-0002-9814-1009

REFERENCES

Abatzoglou, J. T., & Williams, A. P. (2016). Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences of the United States of America*, *113*, 11770–11775. https://doi.org/10.1073/pnas.1607171113

Adams, M. A. (2013). Mega-fires, tipping points and ecosystem services: Managing forests and woodlands in an uncertain future. *Forest Ecology and Management*, *294*, 250–261. https://doi.org/10.1016/j.foreco.2012.11.039

Alló, M., & Loureiro, M. L. (2020). Assessing preferences for wildfire prevention policies in Spain. *Forest Policy and Economics*, *115*, 102145. https://doi.org/10.1016/j.forpol.2020.102145

Andela, N., Morton, D. C., Giglio, L., Chen, Y., Van der Werf, G. R., Kasibhatla, P. S., DeFries, R. S., Collatz, G. J., Hantson, S., Kloster, S., Bachelet, D., Forrest, M., Lasslop, G., Li, F., Mangeon, S., Melton, J. R., Yue, C., & Randerson, J. T. (2017). A human-driven decline in global burned area. *Science*, *356*, 1356–1362. https://doi.org/10.1126/science.aal4108

Anthony, C. R., Foster, L. J., Hagen, C. A., & Dugger, K. M. (2021). Acute and lagged fitness consequences for a sagebrush obligate in a post mega-wildfire landscape. *Ecology and Evolution*. https://doi.org/10.1002/ece3.8488

Archibald, S., Lehmann, C. E. R., Belcher, C. M., Bond, W. J., Bradstock, R. A., Daniau, A.-L., Dexter, K. G., Forrestel, E. J., Greve, M., He, T., Higgins, S. I., Hoffmann, W. A., Lamont, B. B., McGlinn, D. J., Moncrieff, G. R., Osborne, C. P., Pausas, J. G., Price, O., Ripley, B. S., … Zanne, A. E. (2018). Biological and geophysical feedbacks with fire in the Earth system. *Environmental Research Letters*, *13*, 033003. https://doi.org/10.1088/1748-9326/aa9ead

Bartlett, T., Leonard, M., & Morgan, G. (2007). The megafire phenomenon: some Australian perspective. The 2007 Institute of Foresters of Australia and New Zealand Institute of Forestry Conference: Program, Abstracts and Papers, Institute of Foresters of Australia, Canberra.

Barton, A. M., & Poulos, H. M. (2019). Response of Arizona cypress (*Hesperocyparis arizonica*) to the Horseshoe Two Megafire in a south-eastern Arizona Sky Island mountain range. *International Journal of Wildland Fire*, *28*, 62–69. https://doi.org/10.1071/WF18133

Bliege Bird, R., Codding, B. F., Kauhanen, P. G., & Bird, D. W. (2012). Aboriginal hunting buffers climate-driven fire-size variability in Australia's spinifex grasslands. *Proceedings of the National Academy of Sciences of the United States of America*, *109*, 10287–10292. https://doi.org/10.1073/pnas.1204585109

Boer, M. M., deDios, V. R., & Bradstock, R. A. (2020). Unprecedented burn area of Australian mega forest fires. *Nature Climate Change*, *10*, 170–172. https://doi.org/10.1038/s41558-020-0716-1

Bowman, D. M. J. S., Balch, J., Artaxo, P., Bond, W. J., Cochrane, M. A., D'Antonio, C. M., DeFries, R., Johnston, F. H., Keeley, J. E., Krawchuk, M. A., Kull, C. A., Mack, M., Moritz, M. A., Pyne, S., Roos, C. I., Scott, A. C., Sodhi, N. S., & Swetnam, T. W. (2011). The human dimension of fire regimes on Earth: The human dimension of fire regimes on Earth. *Journal of Biogeography*, *38*, 2223–2236. https://doi.org/10.1111/j.1365-2699.2011.02595.x

Bowman, D. M. J. S., Kolden, C. A., Abatzoglou, J. T., Johnston, F. H., van derWerf, G. R., & Flannigan, M. (2020). Vegetation fires in the Anthropocene. *Nature Reviews Earth & Environment*, *1*, 500–515. https://doi.org/10.1038/s43017-020-0085-3

Bowman, D. M. J. S., Williamson, G. J., Abatzoglou, J. T., Kolden, C. A., Cochrane, M. A., & Smith, A. M. S. (2017). Human exposure and sensitivity to globally extreme wildfire events. *Nature Ecology & Evolution*, *1*, 0058. https://doi.org/10.1038/s41559-016-0058

Cochrane, M. A. (2003). Fire science for rainforests. *Nature*, *421*, 913–919. https://doi.org/10.1038/nature01437

Diakakis, M., Nikolopoulos, E. I., Mavroulis, S., Vassilakis, E., & Korakaki, E. (2017). Observational evidence on the effects of mega-fires on the frequency of hydrogeomorphic hazards. The case of the Peloponnese fires of 2007 in Greece. *Science of the Total Environment*, *592*, 262–276. https://doi.org/10.1016/j.scitotenv.2017.03.070

Doerr, S. H., & Santín, C. (2016). Global trends in wildfire and its impacts: Perceptions versus realities in a changing world. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*, 20150345.

Driscoll, D. A., Balouch, S., Burns, T. J., Garvey, T. F., Wevill, T., Yokochi, K., & Doherty, T. S. (2019). A critique of "countryside biogeography" as a guide to research in human-dominated landscapes. *Journal of Biogeography*, *46*, 2850–2859. https://doi.org/10.1111/jbi.13712

Duane, A., Castellnou, M., & Brotons, L. (2021). Towards a comprehensive look at global drivers of novel extreme wildfire events. *Climatic Change*, *165*, 43. https://doi.org/10.1007/s10584-021-03066-4

Ellis, E. C., Gauthier, N., Klein Goldewijk, K., Bliege Bird, R., Boivin, N., Díaz, S., Fuller, D. Q., Gill, J. L., Kaplan, J. O., Kingston, N., Locke, H., McMichael, C. N. H., Ranco, D., Rick, T. C., Shaw, M. R., Stephens, L., Svenning, J.-C., & Watson, J. E. M. (2021). People have shaped most of terrestrial nature for at least 12,000 years. *Proceedings of the National Academy of Sciences of the United States of America*, *118*, e2023483118. https://doi.org/10.1073/pnas.2023483118

Fidelis, A., Alvarado, S., Barradas, A., & Pivello, V. (2018). The year 2017: Megafires and management in the Cerrado. *Fire*, *1*, 49. https://doi.org/10.3390/fire1030049

Fletcher, M.-S., Hamilton, R., Dressler, W., & Palmer, L. (2021). Indigenous knowledge and the shackles of wilderness. *Proceedings of the National Academy of Sciences of the United States of America*, *118*, e2022218118. https://doi.org/10.1073/pnas.2022218118

Fletcher, M.-S., Romano, A., Connor, S., Mariani, M., & Maezumi, S. Y. (2021). Catastrophic bushfires, Indigenous fire knowledge and reframing science in southeast Australia. *Fire*, *4*, 61. https://doi.org/10.3390/fire4030061

French, B. J., Prior, L. D., Williamson, G. J., & Bowman, D. M. J. S. (2016). Cause and effects of a megafire in sedge-heathland in the Tasmanian temperate wilderness. *Australian Journal of Botany*, *64*, 513–525. https://doi.org/10.1071/BT16087

Fusco, E. J., Finn, J. T., Balch, J. K., Nagy, R. C., & Bradley, B. A. (2019). Invasive grasses increase fire occurrence and frequency across US ecoregions. *Proceedings of the National Academy of Sciences of the United States of America*, *116*, 23594–23599. https://doi.org/10.1073/pnas.1908253116

Gaines, S. D., & Denny, M. W. (1993). The largest, smallest, highest, lowest, longest, and shortest: Extremes in ecology. *Ecology*, *74*, 1677–1692. https://doi.org/10.2307/1939926

General Office of the State Council. (2018). Regulations on fire prevention for forests. *Decree of the State Council of the People's Republic of China*, *541*. https://www.gov.cn/flfg/2008-12/05/content_1171407.htm

Godfree, R. C., Knerr, N., Encinas-Viso, F., Albrecht, D., Bush, D., Christine Cargill, D., Clements, M., Gueidan, C., Guja, L. K., Harwood, T., Joseph, L., Lepschi, B., Nargar, K., Schmidt-Lebuhn, A., & Broadhurst, L. M. (2021). Implications of the 2019–2020 megafires for the biogeography and conservation of Australian vegetation. *Nature Communications*, *12*, 1023. https://doi.org/10.1038/s41467-021-21266-5

Groisman, P., Shugart, H., Kicklighter, D., Henebry, G., Tchebakova, N., Maksyutov, S., Monier, E., Gutman, G., Gulev, S., Qi, J., Prishchepov, A., Kukavskaya, E., Porfiriev, B., Shiklomanov, A., Loboda, T., Shiklomanov, N., Nghiem, S., Bergen, K., Albrechtová, J., … Zolina, O. (2017). Northern Eurasia Future Initiative (NEFI): Facing the challenges and pathways of global change in the twenty-first century. *Progress in Earth and Planetary Science*, *4*, 1–48. https://doi.org/10.1186/s40645-017-0154-5

Gutiérrez, N. A., Medina, L. C., Lackington, T. R., & Kovalskys, D. S. (2020). De protagonistas a denegados: El doble trauma en un caso de relocalización post-incendio en Valparaíso, Chile. *Scripta Nova. Revista Electrónica De Geografía Y Ciencias Sociales*, *24*, 636.

Gutschick, V. P., & BassiriRad, H. (2003). Extreme events as shaping physiology, ecology, and evolution of plants: Toward a unified definition and evaluation of their consequences. *New Phytologist*, *160*, 21–42. https://doi.org/10.1046/j.1469-8137.2003.00866.x

He, T., Lamont, B. B., & Pausas, J. G. (2019). Fire as a key driver of Earth's biodiversity. *Biological Reviews*, *94*(*6*), 1983–2010. https://doi.org/10.1111/brv.12544

IPCC (2021). Climate Change 2021: the physical science basis. Contribution of Working group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L.Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. InPress.

Johnson, A. F., & Lidström, S. (2018). The balance between concepts and complexity in ecology. *Nature Ecology & Evolution*, *2*, 585–587. https://doi.org/10.1038/s41559-018-0507-5

Jolly, W. M., Cochrane, M. A., Freeborn, P. H., Holden, Z. A., Brown, T. J., Williamson, G. J., & Bowman, D. M. (2015). Climate-induced variations in global wildfire danger from 1979 to 2013. *Nature Communications*, *6*, 1–11. https://doi.org/10.1038/ncomms8537

Jung, T. S. (2020). Bats in the changing boreal forest: Response to a megafire by endangered little brown bats (*Myotis lucifugus*). *Écoscience*, *27*, 59–70.

Katz, R. W., Brush, G. S., & Parlange, M. B. (2005). Statistics of extremes: Modeling ecological disturbances. *Ecology*, *86*, 1124–1134. https://doi.org/10.1890/04-0606

Keeley, J. E., & Syphard, A. D. (2021). Large California wildfires: 2020 fires in historical context. *Fire Ecology*, *17*, 22. https://doi.org/10.1186/s42408-021-00110-7

Keeley, J. E., & Zedler, P. H. (2009). Large, high-intensity fire events in southern California shrublands: Debunking the fine-grain age patch model. *Ecological Applications*, *19*, 69–94. https://doi.org/10.1890/08-0281.1

Kelly, L. T., Giljohann, K. M., Duane, A., Aquilué, N., Archibald, S., Batllori, E., Bennett, A. F., Buckland, S. T., Canelles, Q., Clarke, M. F., Fortin, M.-J., Hermoso, V., Herrando, S., Keane, R. E., Lake, F. K., McCarthy, M. A., Morán-Ordóñez, A., Parr, C. L., Pausas, J. G., … Brotons, L. (2020). Fire and biodiversity in the Anthropocene. *Science*, *370*, eabb0355. https://doi.org/10.1126/science.abb0355

Keyser, A. R., & Westerling, A. L. (2019). Predicting increasing high severity area burned for three forested regions in the western United States using extreme value theory. *Forest Ecology and Management*, *432*, 694–706. https://doi.org/10.1016/j.foreco.2018.09.027

Khorshidi, M. S., Dennison, P. E., Nikoo, M. R., AghaKouchak, A., Luce, C. H., & Sadegh, M. (2020). Increasing concurrence of wildfire drivers tripled megafire critical danger days in southern California between 1982 and 2018. *Environmental Research Letters*, *15*, 104002. https://doi.org/10.1088/1748-9326/abae9e

Langpap, C., & Wu, J. (2021). Preemptive incentives and liability rules for wildfire risk management. *American Journal of Agricultural Economics*, *103*, 1783–1801. https://doi.org/10.1111/ajae.12220

Lapere, R., Mailler, S., & Menut, L. (2021). The 2017 mega-fires in central Chile: Impacts on regional atmospheric composition and meteorology assessed from satellite data and chemistry-transport modeling. *Atmosphere*, *12*, 344. https://doi.org/10.3390/atmos12030344

Lee, J. S., Callaghan, C. T., & Cornwell, W. K. (2021). Using citizen science to measure recolonisation of birds after the Australian 2019–2020 mega-fires. *Austral Ecology*. https://doi.org/10.1111/aec.13105

Mack, M. C., Bret-Harte, M. S., Hollingsworth, T. N., Jandt, R. R., Schuur, E. A. G., Shaver, G. R., & Verbyla, D. L. (2011). Carbon loss from an unprecedented Arctic tundra wildfire. *Nature*, *475*, 489–492. https://doi.org/10.1038/nature10283

Maditinos, Z., & Vassiliadis, C. (2011). Mega fires: Can they be managed effectively?*Disaster Prevention and Management: An International Journal*, *20*, 41–52. https://doi.org/10.1108/09653561111111072

Maezumi, S. Y., Robinson, M., deSouza, J., Urrego, D. H., Schaan, D., Alves, D., & Iriarte, J. (2018). New insights from pre-Columbian land use and fire management in Amazonian dark earth forests. *Frontiers in Ecology and Evolution*, *6*, 111. https://doi.org/10.3389/fevo.2018.00111

Mancini, L. D., Barbati, A., & Corona, P. (2017). Geospatial analysis of woodland fire occurrence and recurrence in Italy. *Annals of Silvicultural Research*, *41*, 41–47.

Moritz, M. A. (1997). Analyzing extreme disturbance events: Fire in los padres national forest. *Ecological Applications*, *7*, 1252–1262.

Nimmo, D. G., Carthey, A. J. R., Jolly, C. J., & Blumstein, D. T. (2021). Welcome to the Pyrocene: Animal survival in the age of megafire. *Global Change Biology*, 5684–5693. https://doi.org/10.1111/gcb.15834

Nuñez, M. A., Chiuffo, M. C., Pauchard, A., & Zenni, R. D. (2021). Making ecology really global. *Trends in Ecology & Evolution*, *36*, 766–769. https://doi.org/10.1016/j.tree.2021.06.004

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., & Kassem, K. R. (2001). Terrestrial ecoregions of the world: A new map of life on earth. *BioScience*, *51*, 933.

Omi, P. N. (2005). *Forest fires: A reference handbook*. ABC-CLIO.

Ozturk, M., Gucel, S., Kucuk, M., & Sakcali, S. (2010). Forest diversity, climate change and forest fires in the Mediterranean region of Turkey. *Journal of Environmental Biology*, *31*, 1–9.

Pausas, J. G., & Keeley, J. E. (2021). Wildfires and global change. *Frontiers in Ecology and the Environment*, *19*, 387–395. https://doi.org/10.1002/fee.2359

Pausas, J. G., & Parr, C. L. (2018). Towards an understanding of the evolutionary role of fire in animals. *Evolutionary Ecology*, *32*, 113–125. https://doi.org/10.1007/s10682-018-9927-6

Pulsford, S. A., Lindenmayer, D. B., & Driscoll, D. A. (2016). A succession of theories: Purging redundancy from disturbance theory: Purging redundancy from disturbance theory. *Biological Reviews*, *91*, 148–167. https://doi.org/10.1111/brv.12163

Regan, H. M., Colyvan, M., & Burgman, M. A. (2002). A taxonomy and treatment of uncertainty for ecology and conservation biology. *Ecological Applications*, *12*, 618–628.

Santos, X., Belliure, J., Gonçalves, J., & Pausas, J. G. (2022). Resilience of reptiles to megafires. *Ecological Applications*, 32, e2518. https://doi.org/10.1002/eap.2518

Schofield, L. N., Eyes, S. A., Siegel, R. B., & Stock, S. L. (2020). Habitat selection by spotted owls after a megafire in Yosemite National Park. *Forest Ecology and Management*, *478*, 118511. https://doi.org/10.1016/j.foreco.2020.118511

Smith, D. S., Fettig, S. M., & Bowker, M. A. (2016). Elevated Rocky Mountain elk numbers prevent positive effects of fire on quaking aspen (*Populus tremuloides*) recruitment. *Forest Ecology and Management*, *362*, 46–54. https://doi.org/10.1016/j.foreco.2015.11.020

Stephens, S. L., Burrows, N., Buyantuyev, A., Gray, R. W., Keane, R. E., Kubian, R., Liu, S., Seijo, F., Shu, L., Tolhurst, K. G., & van-Wagtendonk, J. W. (2014). Temperate and boreal forest megafires: Characteristics and challenges. *Frontiers in Ecology and the Environment*, *12*, 115–122. https://doi.org/10.1890/120332

Stephens, S. L., & Ruth, L. W. (2005). Federal forest-fire policy in the United States. *Ecological Applications*, *15*, 532–542. https://doi.org/10.1890/04-0545

Tedim, F., Leone, V., Amraoui, M., Bouillon, C., Coughlan, M., Delogu, G., Fernandes, P., Ferreira, C., McCaffrey, S., McGee, T., Parente, J., Paton, D., Pereira, M., Ribeiro, L., Viegas, D., & Xanthopoulos, G. (2018). Defining extreme wildfire events: Difficulties, challenges, and impacts. *Fire*, *1*, 9. https://doi.org/10.3390/fire1010009

Tedim, F., Remelgado, R., Carvalho, S., & Martins, J. (2015). The largest forest fires in Portugal: The constraints of burned area size on the comprehension of fire severity. *Journal of Environmental Biology*, *36*, 133–143.

Trisos, C. H., Auerback, J., & Katti, M. (2021). Decoloniality and anti-oppressive practices for a more ethical ecology. *Nature Ecology & Evolution*, *5*, 1205–1212. https://doi.org/10.1038/s41559-021-01460-w

United Nations Environment Programme (2022). *Spreading like wildfire – The rising threat of extraordinary landscape fires. A UNEP Rapid Response Assessment*. UNEP, Nairobi.

Walker, X. J., Rogers, B. M., Baltzer, J. L., Cumming, S. G., Day, N. J., Goetz, S. J., Johnstone, J. F., Schuur, E. A. G., Turetsky, M. R., & Mack, M. C. (2018). Cross-scale controls on carbon emissions from boreal forest megafires. *Global Change Biology*, *24*, 4251–4265. https://doi.org/10.1111/gcb.14287

Whitney, J. E., Gido, K. B., Pilger, T. J., Propst, D. L., & Turner, T. F. (2015). Consecutive wildfires affect stream biota in cold- and warmwater dryland river networks. *Freshwater Science*, *34*, 1510–1526. https://doi.org/10.1086/683391

Williams, J. E. (2010). The 1910 Fires a century later: Could they happen again. Proceedings of the Inland Empire Society of American Foresters Annual Meeting, Wallace, ID, USA

Williams, J. E. (2013). Exploring the onset of high-impact megafires through a forest land management prism. *Forest Ecology and Management*, *294*, 4–10. https://doi.org/10.1016/j.foreco.2012.06.030

Williams, J. E., Albright, D. O., Hoffmann, A. A., Eritsov, A. N., Moore, P. F., Mendes de Morais, J. C., Leonard, M., San Miguel-Ayanz, J., Xanthopoulos, G., & Van Lierop, P. (2011). Findings and implications from a coarse-scale global assessment of recent selected mega-fires. International Wildland Fire Conference, South Africa.

Williams, J. E., Hamilton, L., Mann, R., Rounsaville, M., Leonard, H., Daniels, O., & Bunnell, D. (2005). *The mega-fire phenomenon: Toward a more effective management model. A concept paper.* Brookings Institution. http://www.bushfirecrc.com/sites/default/files/managed/resource/mega-fire_concept_paper_september_20_

Wu, C., Venevsky, S., Sitch, S., Mercado, L. M., Huntingford, C., & Staver, A. C. (2021). Historical and future global burned area with changing climate and human demography. *One Earth*, *4*, 517–530. https://doi.org/10.1016/j.oneear.2021.03.002

Zhuang, Y., Fu, R., Santer, B. D., Dickinson, R. E., & Hall, A. (2021). Quantifying contributions of natural variability and anthropogenic forcings on increased fire weather risk over the western United States. *Proceedings of the National Academy of Sciences of the United States of America*, *118*, e2023483118. https://doi.org/10.1073/pnas.2111875118

BIOSKETCHES

Grant Linley is a PhD Candidate at Charles Sturt University's Gulbali Institute and Chris Jolly is a Postdoctoral Research Fellow at Macquarie University's School of Natural Sciences, and both study the effects of megafire on wildlife. This team is composed of fire scientists from around the world.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Linley, G. D., Jolly, C. J., Doherty, T. S., Geary, W. L., Armenteras, D., Belcher, C. M., Bliege Bird, R., Duane, A., Fletcher, M.-S., Giorgis, M. A., Haslem, A., Jones, G. M., Kelly, L. T., Lee, C. K. F., Nolan, R. H., Parr, C. L., Pausas, J. G., Price, J. N., Regos, A., ... Nimmo, D. G. (2022). What do you mean, 'megafire'? *Global Ecology and Biogeography*, *00*, 1–17. https://doi.org/10.1111/geb.13499

APPENDIX A

DATA SOURCES

Abella, S. R. & Fornwalt, P. J. (2015) Ten years of vegetation assembly after a North American mega fire. *Global Change Biology*, *21*, 789–802.

Adams, M. A. (2013) Mega-fires, tipping points and ecosystem services: Managing forests and woodlands in an uncertain future. *Forest Ecology and Management*, *294*, 250–261.

Ager, A. A., Day, M. A., McHugh, C. W., Short, K., Gilbertson-Day, J., Finney, M. A. & Calkin, D. E. (2014) Wildfire exposure and fuel management on western US national forests. *Journal of Environmental Management*, *145*, 54–70.

Alló, M. & Loureiro, M. L. (2020) Assessing preferences for wildfire prevention policies in Spain. *Forest Policy and Economics*, *115*, 102145.

Anthony, C. R., Foster, L. J., Hagen, C. A. & Dugger, K. M. (2021). Acute and lagged fitness consequences for a sagebrush obligate in a post mega-wildfire landscape. *Ecology and Evolution*.

Baranowski, K., Faust, C. L., Eby, P. & Bharti, N. (2021). Quantifying the impacts of Australian bushfires on native forests and gray-headed flying foxes. *Global Ecology and Conservation*, *27*, e01566.

de la Barrera, F., Barraza, F., Favier, P., Ruiz, V. & Quense, J. (2018) Megafires in Chile 2017: Monitoring multiscale environmental impacts of burned ecosystems. *Science of The Total Environment*, *637*, 1526–1536.

Barton, A. M. & Poulos, H. M. (2019) Response of Arizona cypress (*Hesperocyparis arizonica*) to the Horseshoe Two Megafire in a south-eastern Arizona Sky Island mountain range. *International Journal of Wildland Fire*, *28*, 62–69.

Berroeta, H., Pinto de Carvalho, L., Castillo-Sepúlveda, J. & Opazo, L. (2021). Sociospatial ties and postdisaster reconstruction: An analysis of the assemblage in the mega-fire of Valparaíso. *Journal of community psychology*, *49*, 95–117.

Boer, M. M., de Dios, V. R. & Bradstock, R. A. (2020) Unprecedented burn area of Australian mega forest fires. *Nature Climate Change*, *10*, 170–172.

Bowman, D. M. J. S., Perry, G. L. W., Higgins, S. I., Johnson, C. N., Fuhlendorf, S. D. & Murphy, B. P. (2016) Pyrodiversity is the coupling of biodiversity and fire regimes in food webs. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*, 20150169.

Bowman, D. M. J. S., Williamson, G. J., Price, O. F., Ndalila, M. N. & Bradstock, R. A. (2021) Australian forests, megafires and the risk of dwindling carbon stocks. *Plant, Cell & Environment*, *44*, 347–355.

Brookes, W., Daniels, L. D., Copes-Gerbitz, K., Baron, J. N. & Carroll, A. L. (2021). A disrupted historical fire regime in central British Columbia. *Frontiers in Ecology and Evolution*, *9*, 676961.

Bytnerowicz, A., Hsu, Y.-M., Percy, K., Legge, A., Fenn, M. E., Schilling, S., Frączek, W. & Alexander, D. (2016) Ground-level air pollution changes during a boreal wildland mega-fire. *Science of The Total Environment*, *572*, 755–769.

Cai, W., Yang, J., Liu, Z., Hu, Y. & Weisberg, P. J. (2013) Post-fire tree recruitment of a boreal larch forest in Northeast China. *Forest Ecology and Management*, *307*, 20–29.

Calhoun, K. L., Chapman, M., Tubbesing, C., McInturff, A., Gaynor, K. M., Van Scoyoc, A., Wilkinson, C. E., Parker-Shames, P., Kurz, D. & Brashares, J. (2021). Spatial overlap of wildfire and biodiversity in California highlights gap in non-conifer fire research and management. *Diversity and Distributions*.

Casas, Á., García, M., Siegel, R. B., Koltunov, A., Ramírez, C. & Ustin, S. (2016) Burned forest characterization at single-tree level with airborne laser scanning for assessing wildlife habitat. *Remote Sensing of Environment*, *175*, 231–241.

Coen, J. L., Stavros, E. N. & Fites-Kaufman, J. A. (2018) Deconstructing the King megafire. *Ecological Applications*, *28*, 1565–1580.

Collins, L., Bradstock, R. A., Clarke, H., Clarke, M. F., Nolan, R. H. & Penman, T. D. (2021) The 2019/2020 mega-fires exposed Australian ecosystems to an unprecedented extent of high-severity fire. *Environmental Research Letters*, *16*, 044029.

Crandall, T., Jones, E., Greenhalgh, M., Frei, R. J., Griffin, N., Severe, E., Maxwell, J., Patch, L., St. Clair, S. I., Bratsman, S., Merritt, M., Norris, A. J., Carling, G. T., Hansen, N., St. Clair, S. B. & Abbott, B. W. (2021). Megafire affects stream sediment flux and dissolved organic matter reactivity, but land use dominates nutrient dynamics in semiarid watersheds. *PloS one*, *16*, e0257733.

Crates, R., Rayner, L., Stojanovic, D., Scheele, B. C., Roff, A., MacKenzie, J. & Heinsohn, R. (2021). Poor-quality monitoring data underestimate the impact of Australia's megafires on a critically endangered songbird. *Diversity and Distributions*.

Davies, K. W., Boyd, C. S., Bates, J. D. & Hulet, A. (2016) Winter grazing can reduce wildfire size, intensity and behaviour in a shrub-grassland. *International Journal of Wildland Fire*, *25*, 191–199.

Diakakis, M., Nikolopoulos, E. I., Mavroulis, S., Vassilakis, E. & Korakaki, E. (2017) Observational evidence on the effects of mega-fires on the frequency of hydrogeomorphic hazards. The case of the Peloponnese fires of 2007 in Greece. *Science of The Total Environment*, *592*, 262–276.

Dickson-Hoyle, S., Ignace, R. E., Ignace, M. B., Hagerman, S. M., Daniels, L. D. & Copes-Gerbitz, K. (2021). Walking on two legs: a pathway of Indigenous restoration and reconciliation in fire-adapted landscapes. *Restoration Ecology*, e13566.

Dimitrakopoulos, A., Gogi, C., Stamatelos, G. & Mitsopoulos, I. (2011) Statistical analysis of the fire environment of large forest fires (>1000 ha) in Greece. *Polish Journal of Environmental Studies*, *20*, 327–332.

Fernández-Guisuraga, J. M., Verrelst, J., Calvo, L. & Suárez-Seoane, S. (2021). Hybrid inversion of radiative transfer models based on high spatial resolution satellite reflectance data improves fractional vegetation cover retrieval in heterogeneous ecological systems after fire. *Remote Sensing of Environment*, *255*, 112304.

Fernández-Manso, A., Quintano, C. & Roberts, D. A. (2020) Can landsat-derived variables related to energy balance improve understanding of burn severity from current operational techniques? *Remote Sensing*, *12*, 890.

FerreirA-leiTe, F., Lourenço, L. & Bento-Gonçalves, A. (2013). Large forest fires in mainland Portugal, brief characterization. *Méditerranée. Revue géographique des pays méditerranéens/Journal of Mediterranean geography*, *121*, 53–65.

Fidelis, A., Alvarado, S., Barradas, A. & Pivello, V. (2018) The year 2017: Megafires and management in the Cerrado. *Fire*, *1*, 49.

French, B. J., Prior, L. D., Williamson, G. J. & Bowman, D. M. J. S. (2016) Cause and effects of a megafire in sedge-heathland in the Tasmanian temperate wilderness. *Australian Journal of Botany*, *64*, 513–525.

Gallagher, R. V., Allen, S., Mackenzie, B. D. E., Yates, C. J., Gosper, C. R., Keith, D. A., Merow, C., White, M. D., Wenk, E., Maitner, B. S., He, K., Adams, V. M. & Auld, T. D. (2021) High fire frequency and the impact of the 2019–2020 megafires on Australian plant diversity. *Diversity and Distributions*, *27*, 1166–1179.

Ganey, J. L., Wan, H. Y., Cushman, S. A. & Vojta, C. D. (2017) Conflicting perspectives on spotted owls, wildfire, and forest restoration. *Fire Ecology*, *13*, 146–165.

Garcia, M., Saatchi, S., Casas, A., Koltunov, A., Ustin, S., Ramirez, C., Garcia-Gutierrez, J. & Balzter, H. (2017) Quantifying biomass consumption and carbon release from the California Rim fire by integrating airborne LiDAR and Landsat OLI data. *Journal of Geophysical Research: Biogeosciences*, *122*, 340–353.

García-Carmona, M., Marín, C., García-Orenes, F. & Rojas, C. (2021). Contrasting organic amendments induce different short-term responses in soil abiotic and biotic properties in a fire-affected native Mediterranean forest in Chile. *Journal of Soil Science and Plant Nutrition*, *21*(3), 2105-2114.

García-Llamas, P., Suárez-Seoane, S., Taboada, A., Fernández-García, V., Fernández-Guisuraga, J. M., Fernández-Manso, A., Quintano, C., Marcos, E. & Calvo, L. (2019a) Assessment of the influence of biophysical properties related to fuel conditions on fire severity using remote sensing techniques: a case study on a large fire in NW Spain. *International Journal of Wildland Fire*, *28*, 512–520.

García-Llamas, P., Suárez-Seoane, S., Taboada, A., Fernández-Manso, A., Quintano, C., Fernández-García, V., Fernández-Guisuraga, J. M., Marcos, E. & Calvo, L. (2019b) Environmental drivers of fire severity in extreme fire events that affect Mediterranean pine forest ecosystems. *Forest Ecology and Management*, *433*, 24–32.

Geary, W. L., Buchan, A., Allen, T., Attard, D., Bruce, M. J., Collins, L., Ecker, T. E., Fairman, T. A., Hollings, T., Loeffler, E., Muscatello, A., Parkes, D., Thomson, J., White, M. & Kelly, E. (2021). Responding to the biodiversity impacts of a megafire: A case study from south-eastern Australia's Black Summer. *Diversity and Distributions*.

General Office of the State Council (2018). Regulations on Fire Prevention for Forests. *Decree of the State Council of the People's Republic of China*. *541*. http://www.gov.cn/flfg/2008-12/05/content_1171407.htm

Gill, A. M. & Stephens, S. L. (2009) Scientific and social challenges for the management of fire-prone wildland–urban interfaces. *Environmental Research Letters*, *4*, 034014.

Godfree, R. C., Knerr, N., Encinas-Viso, F., Albrecht, D., Bush, D., Christine Cargill, D., Clements, M., Gueidan, C., Guja, L. K., Harwood, T., Joseph, L., Lepschi, B., Nargar, K., Schmidt-Lebuhn, A. & Broadhurst, L. M. (2021) Implications of the 2019–2020 megafires for the biogeography and conservation of Australian vegetation. *Nature Communications*, *12*, 1023.

Groisman, P., Shugart, H., Kicklighter, D., Henebry, G., Tchebakova, N., Maksyutov, S., Monier, E., Gutman, G., Gulev, S., Qi, J., Prishchepov, A., Kukavskaya, E., Porfiriev, B., Shiklomanov, A., Loboda, T., Shiklomanov, N., Nghiem, S., Bergen, K., Albrechtová, J., Chen, J., Shahgedanova, M., Shvidenko, A., Speranskaya, N., Soja, A., de Beurs, K., Bulygina, O., McCarty, J., Zhuang, Q. & Zolina, O. (2017) Northern Eurasia Future Initiative (NEFI): facing the challenges and pathways of global change in the twenty-first century. *Progress in Earth and Planetary Science*, *4*, 1–48.

Guerra, C., Plaza, H. & Vargas, J. (2018). Estrés postraumático en adolescentes expuestos a un mega incendio: Asociaciones con factores cognitivos y emocionales. *Psicoperspectivas*, *17*, 175–186.

Gustafsson, L., Berglind, M., Granström, A., Grelle, A., Isacsson, G., Kjellander, P., Larsson, S., Lindh, M., Pettersson, L. B., Strengbom, J., Stridh, B., Sävström, T., Thor, G., Wikars, L.-O. & Mikusiński, G. (2019) Rapid ecological response and intensified knowledge accumulation following a north European mega-fire. *Scandinavian Journal of Forest Research*, *34*, 234–253.

Gustafsson, L., Granath, G., Nohrstedt, H. Ö., Leverkus, A. B. & Johansson, V. (2021). Burn severity and soil chemistry are weak drivers of early vegetation succession following a boreal mega-fire in a production forest landscape. *Journal of Vegetation Science*, *32*, e12966.

Gutiérrez, N. A., Medina, L. C., Lackington, T. R. & Kovalskys, D. S. (2020). De protagonistas a denegados: el doble trauma en un caso de relocalización post-incendio en Valparaíso, Chile. *Scripta Nova. Revista Electrónica de Geografía y Ciencias Sociales*, *24*, 636.

Hagmann, R. K., Merschel, A. G. & Reilly, M. J. (2019) Historical patterns of fire severity and forest structure and composition in a landscape structured by frequent large fires: Pumice Plateau ecoregion, Oregon, USA. *Landscape Ecology*, *34*, 551–568.

Jia, S., Kim, S. H., Nghiem, S. V., Doherty, P. & Kafatos, M. C. (2020) Patterns of population displacement during mega-fires in California detected using Facebook Disaster Maps. *Environmental Research Letters*, *15*, 074029.

Jolly, C. J., Dickman, C. R., Doherty, T. S., van Eeden, L. M., Geary, W. L., Legge, S. M., Woinarski, J. C. Z. & Nimmo, D. G. (2021). Animal mortality during fire. *Global Change Biology*.

Jolly, C. J., Moore, H. A., Cowan, M. A., Cremona, T., Dunlop, J. A., Legge, S. M., Linley, G. D., Miritis, V., Woinarski, J. C. Z. & Nimmo, D. G. (2022). Taxonomic revision reveals potential impacts of Black Summer megafires on a cryptic species. *Pacific Conservation Biology*.

Jones, B. A., Thacher, J. A., Chermak, J. M. & Berrens, R. P. (2016a) Wildfire smoke health costs: a methods case study for a Southwestern US 'mega-fire.' *Journal of Environmental Economics and Policy*, *5*, 181–199.

Jones, B. A. & McDermott, S. (2021a). The local labor market impacts of US megafires. *Sustainability*, *13*, 9078.

Jones, B. A. & McDermott, S. (2021b). Infant health outcomes in mega-fire affected communities. *Applied Economics Letters*.

Jones, G. M., Gutiérrez, R., Tempel, D. J., Whitmore, S. A., Berigan, W. J. & Peery, M. Z. (2016b) Megafires: an emerging threat to old-forest species. *Frontiers in Ecology and the Environment*, *14*, 300–306.

Jones, G. M., Kramer, H. A., Berigan, W. J., Whitmore, S. A., Gutiérrez, R. J. & Peery, M. Z. (2021). Megafire causes persistent loss of an old-forest species. *Animal Conservation*, 24, 925–936.

Jung, T. S. (2020) Bats in the changing boreal forest: response to a megafire by endangered little brown bats (*Myotis lucifugus*). *Écoscience*, *27*, 59–70.

Keeley, J. E. & Zedler, P. H. (2009) Large, high-intensity fire events in southern California shrublands: debunking the fine-grain age patch model. *Ecological Applications*, *19*, 69–94.

Khorshidi, M. S., Dennison, P. E., Nikoo, M. R., AghaKouchak, A., Luce, C. H. & Sadegh, M. (2020) Increasing concurrence of wildfire drivers tripled megafire critical danger days in southern California between 1982 and 2018. *Environmental Research Letters*, *15*, 104002.

Kramer, A., Jones, G. M., Whitmore, S. A., Keane, J. J., Atuo, F. A., Dotters, B. P., Sawyer, S. C., Stock, S. L., Gutiérrez, R. J. & Peery, M. Z. (2021) California spotted owl habitat selection in a fire-managed landscape suggests conservation benefit of restoring historical fire regimes. *Forest Ecology and Management*, *479*, 118576.

Kreling, S. E., Gaynor, K. M., McInturff, A., Calhoun, K. L. & Brashares, J. S. (2021). Site fidelity and behavioral plasticity regulate an ungulate's response to extreme disturbance. *Ecology and Evolution*, *11*, 15683–15694.

Lapere, R., Mailler, S. & Menut, L. (2021) The 2017 mega-fires in central Chile: Impacts on regional atmospheric composition and meteorology assessed from satellite data and chemistry-transport modeling. *Atmosphere*, *12*, 344.

Lee, J. S., Callaghan, C. T. & Cornwell, W. K. (2021). Using citizen science to measure recolonisation of birds after the Australian 2019–2020 mega-fires. *Austral Ecology*.

Lindley, T. T., Speheger, D. A., Day, M. A., Murdoch, G. P., Smith, B. R., Nauslar, N. J. & Daily, D. C. (2019) Megafires on the Southern Great Plains. *Journal of Operational Meteorology*, *7*, 164–179.

Liu, Y., Stanturf, J. & Goodrick, S. (2010) Trends in global wildfire potential in a changing climate. *Forest Ecology and Management*, *259*, 685–697.

Mackey, B., Lindenmayer, D., Norman, P., Taylor, C. & Gould, S. (2021). Are fire refugia less predictable due to climate change? *Environmental Research Letters*, *16*, 114028.

Maditinos, Z. & Vassiliadis, C. (2011) Mega fires: can they be managed effectively? *Disaster Prevention and Management: An International Journal*, *20*, 41–52.

Maezumi, S. Y., Robinson, M., de Souza, J., Urrego, D. H., Schaan, D., Alves, D. & Iriarte, J. (2018) New insights from pre-Columbian land use and fire management in Amazonian dark earth forests. *Frontiers in Ecology and Evolution*, *6*, 111.

Mancilla-Ruiz, D., Barrera, F. D. L., González, S. & Huaico, A. (2021). The effects of a megafire on ecosystem services and the pace of landscape recovery. *Land*, *10*, 1388.

Mancini, L. D., Barbati, A. & Corona, P. (2017) Geospatial analysis of woodland fire occurrence and recurrence in Italy. *Annals of Silvicultural Research*, *41*, 41–47.

Martins, P. I., Belém, L. B. C., Szabo, J. K., Libonati, R. & Garcia, L. C. (2022). Prioritising areas for wildfire prevention and post-fire restoration in the Brazilian Pantanal. *Ecological Engineering*, *176*, 106517.

Martinsson, J., Pédehontaa-Hiaa, G., Malmborg, V., Madsen, D. & Rääf, C. (2021) Experimental wildfire induced mobility of radiocesium in a boreal forest environment. *Science of The Total Environment*, *792*, 148310.

Maxwell, C. J., Serra-Diaz, J. M., Scheller, R. M. & Thompson, J. R. (2020) Co-designed management scenarios shape the responses of seasonally dry forests to changing climate and fire regimes. *Journal of Applied Ecology*, *57*, 1328–1340.

Merino, A., Jiménez, E., Fernández, C., Fontúrbel, M. T., Campo, J. & Vega, J. A. (2019) Soil organic matter and phosphorus dynamics after low intensity prescribed burning in forests and shrubland. *Journal of Environmental Management*, *234*, 214–225.

Morgan, G. W., Tolhurst, K. G., Poynter, M. W., Cooper, N., McGuffog, T., Ryan, R., Wouters, M. A., Stephens, N., Black, P., Sheehan, D., Leeson, P., Whight, S. & Davey, S. M. (2020) Prescribed burning in south-eastern Australia: history and future directions. *Australian Forestry*, *83*, 4–28.

Natole Jr, M., Ying, Y., Buyantuev, A., Stessin, M., Buyantuev, V. & Lapenis, A. (2021). Patterns of mega-forest fires in east Siberia will become less predictable with climate warming. *Environmental Advances*, *4*, 100041.

Navarro, K. M., Cisneros, R., O'Neill, S. M., Schweizer, D., Larkin, N. K. & Balmes, J. R. (2016) Air-quality impacts and intake fraction of $PM_{2.5}$ during the 2013 Rim Megafire. *Environmental Science & Technology*, *50*, 11965–11973.

Newsome, T. M. & Spencer, E. E. (2021) Megafires attract avian scavenging but carcasses still persist. *Diversity and Distributions*.

Nimmo, D. G., Carthey, A. J., Jolly, C. J. & Blumstein, D. T. (2021). Welcome to the Pyrocene: Animal survival in the age of megafire. *Global Change Biology*, *27*, 5684–5693.

Oliveira, M., Delerue-Matos, C., Pereira, M. C. & Morais, S. (2020) Environmental particulate matter levels during 2017 large forest fires and megafires in the center region of Portugal: A public health concern? *International Journal of Environmental Research and Public Health*, *17*, 1032.

Pausas, J. G. & Keeley, J. E. (2021) Wildfires and global change. *Frontiers in Ecology and the Environment*, *19*, 387–395.

Pickell, P. D., Chavardès, R. D., Li, S. & Daniels, L. D. (2020). FuelNet: An Artificial Neural Network for Learning and Updating Fuel Types for Fire Research. *IEEE Transactions on Geoscience and Remote Sensing*, *59*, 7338–7352.

Pliscoff, P., Folchi, M., Aliste, E., Cea, D. & Simonetti, J. A. (2020) Chile mega-fire 2017: An analysis of social representation of forest plantation territory. *Applied Geography*, *119*, 102226.

Potter, B. E., & McEvoy, D. (2021). Weather factors associated with extremely large fires and fire growth days. *Earth Interactions*, *25*, 160–176.

Quintano, C., Fernández-Manso, A., Calvo, L. & Roberts, D. A. (2019) Vegetation and soil fire damage analysis based on species distribution modeling trained with multispectral satellite data. *Remote Sensing*, *11*, 1832.

Quintano, C., Fernández-Manso, A. & Roberts, D. A. (2020) Enhanced burn severity estimation using fine resolution ET and MESMA fraction images with machine learning algorithm. *Remote Sensing of Environment*, *244*, 111815.

Robson, B. J., Chester, E. T., Matthews, T. G. & Johnston, K. (2018) Post-wildfire recovery of invertebrate diversity in drought-affected headwater streams. *Aquatic Sciences*, *80*, 21.

San-Miguel-Ayanz, J., Moreno, J. M. & Camia, A. (2013) Analysis of large fires in European Mediterranean landscapes: Lessons learned and perspectives. *Forest Ecology and Management*, *294*, 11–22.

Santos, X., Belliure, J., Gonçalves, J. & Pausas, J. G. (2022). Resilience of reptiles to megafires. *Ecological Applications*, 32, e2518.

Schofield, L. N., Eyes, S. A., Siegel, R. B. & Stock, S. L. (2020) Habitat selection by spotted owls after a megafire in Yosemite National Park. *Forest Ecology and Management*, *478*, 118511.

Siegel, R. B., Eyes, S. A., Tingley, M. W., Wu, J. X., Stock, S. L., Medley, J. R., Kalinowski, R. S., Casas, A., Lima-Baumbach, M. & Rich, A. C. (2019) Short-term resilience of Great Gray Owls to a megafire in California, USA. *The Condor*, *121*, duy019.

Silvestro, R., Saulino, L., Cavallo, C., Allevato, E., Pindozzi, S., Cervelli, E., Conti, P., Mazzoleni, S. & Saracino, A. (2021). The footprint of wildfires on Mediterranean forest ecosystem services in Vesuvius National Park. *Fire*, *4*, 95.

Smith, D. S., Fettig, S. M. & Bowker, M. A. (2016) Elevated Rocky Mountain elk numbers prevent positive effects of fire on quaking aspen (*Populus tremuloides*) recruitment. *Forest Ecology and Management*, *362*, 46–54.

Stephens, S. L., Burrows, N., Buyantuyev, A., Gray, R. W., Keane, R. E., Kubian, R., Liu, S., Seijo, F., Shu, L., Tolhurst, K. G. & van Wagtendonk, J. W. (2014) Temperate and boreal forest megafires: characteristics and challenges. *Frontiers in Ecology and the Environment*, *12*, 115–122.

Stephens, S. L. & Ruth, L. W. (2005) Federal forest-fire policy in the United States. *Ecological Applications*, *15*, 532–542.

Stillman, A. N., Siegel, R. B., Wilkerson, R. L., Johnson, M. & Tingley, M. W. (2019) Age-dependent habitat relationships of a burned forest specialist emphasise the role of pyrodiversity in fire management. *Journal of Applied Ecology*, *56*, 880–890.

Tang, C. Q., He, L.-Y., Su, W.-H., Zhang, G.-F., Wang, H.-C., Peng, M.-C., Wu, Z.-L. & Wang, C.-Y. (2013) Regeneration, recovery and succession of a *Pinus yunnanensis* community five years after a mega-fire in central Yunnan, China. *Forest Ecology and Management*, *294*, 188–196.

Tedim, F., Remelgado, R., Borges, C., Carvalho, S. & Martins, J. (2013) Exploring the occurrence of mega-fires in Portugal. *Forest Ecology and Management*, *294*, 86–96.

Tedim, F., Remelgado, R., Carvalho, S. & Martins, J. (2015) The largest forest fires in Portugal: the constraints of burned area size on the comprehension of fire severity. *Journal of Environmental Biology*, *36*, 133–143.

Torkkola, J. J., Chauvenet, A. L., Hines, H., & Oliver, P. M. (2021). Distributional modelling, megafires and data gaps highlight probable underestimation of climate change risk for two lizards from Australia's montane rainforests. *Austral Ecology*.

Walker, X. J., Rogers, B. M., Baltzer, J. L., Cumming, S. G., Day, N. J., Goetz, S. J., Johnstone, J. F., Schuur, E. A. G., Turetsky, M. R. & Mack, M. C. (2018) Cross-scale controls on carbon emissions from boreal forest megafires. *Global Change Biology*, *24*, 4251–4265.

Waltz, A. E. M., Stoddard, M. T., Kalies, E. L., Springer, J. D., Huffman, D. W. & Meador, A. S. (2014) Effectiveness of fuel reduction treatments: Assessing metrics of forest resiliency and wildfire severity after the Wallow Fire, AZ. *Forest Ecology and Management*, *334*, 43–52.

Ward, M., Tulloch, A. I. T., Radford, J. Q., Williams, B. A., Reside, A. E., Macdonald, S. L., Mayfield, H. J., Maron, M., Possingham, H. P., Vine, S. J., O'Connor, J. L., Massingham, E. J., Greenville, A. C., Woinarski, J. C. Z., Garnett, S. T., Lintermans, M., Scheele, B. C., Carwardine, J., Nimmo, D. G., Lindenmayer, D. B., Kooyman, R. M., Simmonds, J. S., Sonter, L. J. & Watson, J. E. M. (2020) Impact of 2019–2020 mega-fires on Australian fauna habitat. *Nature Ecology & Evolution*, *4*, 1321–1326.

Whitney, J. E., Gido, K. B., Pilger, T. J., Propst, D. L. & Turner, T. F. (2015) Consecutive wildfires affect stream biota in cold- and warmwater dryland river networks. *Freshwater Science*, *34*, 1510–1526.

Williams, J. E. (2013) Exploring the onset of high-impact megafires through a forest land management prism. *Forest Ecology and Management*, *294*, 4–10.

Wintle, B. A., Legge, S. & Woinarski, J. C. Z. (2020) After the megafires: What next for Australian wildlife? *Trends in Ecology & Evolution*, *35*, 753–757.

Wood, C. M. (2021). Optimizing landscape-scale monitoring programmes to detect the effects of megafires. *Diversity and Distributions*.

Wright, B. R., Laffineur, B., Royé, D., Armstrong, G. & Fensham, R. J. (2021). Rainfall-linked megafires as innate fire regime elements in arid Australian spinifex (*Triodia* spp.) grasslands. *Frontiers in Ecology and Evolution*, *9*, 296.

Xaud, H. A. M., Martins, F. da S. R. V. & Santos, J. R. dos (2013) Tropical forest degradation by mega-fires in the northern Brazilian Amazon. *Forest Ecology and Management*, *294*, 97–106.

Xu, W., He, H. S., Fraser, J. S., Hawbaker, T. J., Henne, P. D., Duan, S. & Zhu, Z. (2020) Spatially explicit reconstruction of post-megafire forest recovery through landscape modeling. *Environmental Modelling & Software*, *134*, 104884.

Yang, X., Zhao, C., Yang, Y., Yan, X. & Fan, H. (2021). Statistical aerosol properties associated with fire events from 2002 to 2019 and a case analysis in 2019 over Australia. *Atmospheric Chemistry and Physics*, *21*, 3833–3853.

Zhang, R., Qu, J. J., Liu, Y., Hao, X., Huang, C. & Zhan, X. (2015) Detection of burned areas from mega-fires using daily and historical MODIS surface reflectance. *International Journal of Remote Sensing*, *36*, 1167–1187.