Environmental Science and Policy 146 (2023) 151–161

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Searching the flames: Trends in global and regional public interest in wildfires

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ARTICLE INFO

Keywords:
Google trends
Relative search interest
Forest fires
Bushfires
Natural hazards
Wildfire impacts
Social perceptions

ABSTRACT

Interactions between humans and wildfires have increased in many regions over the last decades driven by climate and land-use changes. A shift towards more adaptive fire management and policies is urgently needed but remains difficult to achieve. Better understanding of public interest in wildfire can facilitate this transition, as the public is a key driver for policy decisions. We used Google Trends to assess temporal patterns (2004–2020) in public interest on wildfires worldwide and in five case study countries (Australia, Canada, Indonesia, Portugal, USA). Public interest consistently shows a cyclic pattern with low background and short-lasting spikes during fire seasons and catastrophic events. Wildfires that receive the most interest worldwide are located in Western countries, especially the USA. There is usually high demand for news on wildfires when spikes in interest happen. Overall global interest in wildfire has risen twice: first for a short period in 2007–2008, concomitant to catastrophic wildfires in California, and again since 2017, probably triggered by a series of catastrophic fire events around the globe. Nevertheless, public interest in wildfire is low when compared with socioeconomically more costly earthquakes or hurricanes. The short and seasonal interest in wildfire may present an important obstacle to the implementation of wildfire mitigation policies that require year-round approaches. However, the fact that the public uses the internet to obtain basic knowledge about wildfire functioning and impacts, especially during the interest spikes, can facilitate targeting awareness campaigns. These could be not only about wildfires but also about broader related environmental issues.

1. Introduction

Changes in climate, land use and population distribution in recent decades have been increasing the interaction between humans and wildfires in many regions around the world, sometimes with catastrophic consequences. For example, anthropogenic changes in climate and land use in recent decades are causing wildfires to be larger and more severe in some fire-prone areas (e.g. Western USA or Australian forests) and more common in other regions where wildfires used to be rare (e.g. Amazonia or the Arctic) (Canadell et al., 2021; dos Reis et al., 2021; Iglesias et al., 2022; Jones et al., 2022; Voronova et al., 2020). Moreover, the fire 'problem' is expected to be exacerbated in the near future, due to projected increases of severe fire weather (i.e. favourable meteorological conditions for the start and spread of fire) and the ongoing growth of the wildland-urban interface (i.e. built-up areas surrounded by vegetation) (Jones et al., 2022; Radeloff et al., 2018; Son et al., 2021).

Over the last few years, catastrophic wildfires have occurred across the world, attracting substantial media and public attention. The label 'catastrophic' has been given for a range of reasons: their rarity (e.g. wildfires in the Arctic in 2020; Witze, 2020), their unprecedented extent (e.g. the Black Summer bushfires in Australia in 2020/21; Bowman et al., 2021), their environmental impacts (e.g. deforestation fires in the Amazonia in 2019; Silveira et al., 2020) or their toll on human lives and the economy (e.g. Attica fires in Greece or the Camp fire in the USA, both in 2018; (CalFire, 2022; Lagouvardos et al., 2019)). Irrespective whether they are catastrophic or not, wildfires are an intrinsic, often essential, perturbation in many ecosystems and thus a widespread natural hazard

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https://doi.org/10.1016/j.envsci.2023.05.008
Received 16 June 2022; Received in revised form 28 April 2023; Accepted 7 May 2023
Available online 24 May 2023

with which we must (re)learn to co-exist (Moritz et al., 2014). This fundamental message is widely accepted within the wildfire scientific and management communities; however, it has not fully reached society and policy makers, many of whom still perceive wildfires as events that can and should be fully eliminated (Cochrane and Bowman, 2021; Doerr and Santin, 2016; North et al., 2015).

Public interest/attention and awareness of wildfires are strong drivers of policy and management decisions (Mccallum and Bury, 2013; Oehl et al., 2017; Pissolito et al., 2020) and they can also influence wildfire activity (e.g. reducing accidental ignitions; Prestemon et al., 2010) and impacts (e.g. increasing community resilience via wildfire preparedness; Chapple et al., 2017). Indeed, there is a growing body of research examining the interest in and perceptions of specific communities or stakeholders to wildfires and associated issues (e.g. Berglez and Lidskog, 2019; Ghasemi et al., 2020; Kouassi et al., 2022; Larsen et al., 2021; Palaiologou et al., 2021; Rosenthal et al., 2021; Sahar et al., 2018; Troumbis, 2021). For example, following the extreme fire seasons of 2017 and 2018 in California, Rosenthal et al. (2021) found that mental and emotional well-being and access to health resources were perceived as the most challenging health concerns that survivors face post-disaster. In Sweden, following the largest forest fire in the country's modern history (2014), Lidskog et al. (2019) found that the public placed little blame on forest companies and fire departments even though the wildfire was human-caused. Here there was a belief that organizations will learn from the experience and take action to limit future wildfires.

Such case studies are very useful in reflecting local and regional perceptions, however, larger-scale and longer-term studies on public interest on wildfires have not been conducted to date, leaving a clear research gap especially at national to global scales. These types of studies have traditionally been very challenging to carry out even at national or finer scales, relying on methods such as face-to-face, telephone, or email surveys, which require considerable time and resources and are subject to nonresponse bias and insincere answering (Mccallum and Bury, 2013). In recent years, internet search data mining has emerged as a powerful alternative tool to estimate public interest. Its main advantages compared to traditional methods are the typically very large sample size, low cost, anonymity, and high temporal frequency. Recent research has shown that information obtained by these methods and traditional surveys is comparable (Troumbis, 2021), but internet search data mining is more effective at tracking the public's interest at larger geographical and temporal scales (Burivalova et al., 2018).

Google Trends (GT), a repository of real-time Google user search patterns, is currently the most common tool for internet search data mining. Google searches on specific topics are considered to reflect the users' interest on them and, thus, the volume of searches over time are a proxy for evolving public interest (Troumbis and Iosifidis, 2020). GT is increasingly used in a wide variety of topics, from epidemiology to psychology or economics. Regarding environmental sciences, GT has been used to track the level of public awareness in key issues such as sustainability, nature conservation, climate change or invasive species (Anderegg and Goldsmith, 2014; Andrew et al., 2016; Fukano and Soga, 2019; Kovalenko et al., 2021; Proulx et al., 2014; Troumbis, 2021), as well as natural hazards such as earthquakes, droughts or rip currents (Habibi and Feld, 2018; Houser et al., 2019; Kam et al., 2021; Kim et al., 2019). There is an increasing body of research, especially on health issues, showing how GT information can be highly valuable for policy making (Wang et al., 2021). Relationships have been found between the application of policy and management practices or public engagement campaigns and the public awareness or interest measured with GT data (Colbourne et al., 2023; Hu and Mcintyre, 2021). Strong public interest can facilitate the prioritisation of specific issues in the policy making agenda (Madani, 2019). In the context of natural hazards, the raising of public awareness after catastrophic events can trigger policy changes (Farhidi et al., 2022), although this is not always the case (Nohrstedt et al., 2021).

In this study we employ internet search data mining with the overall aim to address the lack of large-scale and long-term studies on public interest on wildfires. We use GT to evaluate the long-term (17 years; 2004–2020) trends in public interest in wildfires, both at global and national (Australia, Canada, Indonesia, Portugal and USA) levels. We also explore to what degree public interest is aligned with the geographical and temporal distribution of wildfire, i.e. how temporal and regional trends in web searches relate to specific wildfire events or other indicators of wildfire occurrence and impacts (e.g. area burnt, economic impact, number of casualties). Furthermore, we compare the interest in wildfire with that in other natural hazards, and we also analyse Google's advanced searches by images, news, and videos. Finally, we use GT information to identify the main issues the public is interested in when searching for wildfire-related information on the Web.

2. Materials and methods

2.1. Google Trend Data Mining

Google Trends (https://trends.Google.com/trends/) is a publicly available repository of real-time web user search patterns of individuals that use Google as their search engine. It provides topic/keyword-related data, including search volume index and geographical information about search engine users. It is freely accessible and can be used for comparative topic/keyword search to discover event-triggered spikes in topic search volume, and to assess how interest in a keyword/topic has changed over time (Burivalova et al., 2018). In GT, data are averaged per a specific time unit (e.g. month). First, the absolute number of searches for the specific topic (e.g. wildfire) relative to the total searches in the specific location and time period is calculated. For this, GT data is pulled from a random, unbiased sample of Google searches. Then, to provide specific values, the data are indexed from 1 to 100, where 100 is the maximum search interest for that topic in the selected location over the study period. This index is known as the Relative Search Interest (RSI) or Volume, and ranges from 0% to 100%, with 100% being the specific time when the highest relative search volume was recorded for this topic (Anderegg and Goldsmith, 2014). All the data are given in percent, which eliminates any bias from the fact that the total number of internet users and, thus, the number of searches, have increased over time (see Section 3.5). GT's main constraint is that it shows relative (i.e. not absolute) search-term frequency, therefore, whilst being very effective for detecting spikes or temporal patterns, interest is quantified in relative, but not absolute terms (Burivalova et al., 2018). Furthermore, what motivates internet users to search for each term is not known, so one can assume interest but, for example, cannot derive from those data specific views or behaviours (Ripberger, 2011). Notwithstanding these limitations, the validity of GT data is well supported in the literature (McCallum and Bury, 2014) and GT is emerging as one of the best proxies for gauging public curiosity, attention, and issue salience (Mccallum and Bury, 2013; Mellon, 2014; Vosen and Schmidt, 2011).

Here we used GT to assess the public's interest in wildfire, as well as associated temporal and spatial trends on this search interest (Anderegg and Goldsmith, 2014; Moustakas, 2021; Turki et al., 2020). To do this, we analysed the use of 'wildfire' as a search topic in Google searches from January 2004 (first date from which GT information is available) to February 2020 (both months included). The use of wildfire as a search topic, not as a word, ensures that results exclude those searches with the word 'wildfire' but where it refers to other contexts (e.g. wildfire songs or wildfire in the TV series Games of Thrones). In addition, when considering the 'wildfire' topic, synonyms such as 'bushfires' or 'forests fires' are also included, allowing a more comprehensive inclusion of searches. Also importantly, our analysis included web searches in all major languages (>100) covered by Google Translate.

Data on search interest in wildfires for the study period was obtained both worldwide as well as for five case study countries (results in Section

3.1). Searches per country were defined by the IP location of devices performing web search of the term during the search date. The countries selected were Australia, Canada, Indonesia, Portugal and the United States of America. All these countries experience wildfires frequently and extensively, have had major fire incidents in the study period, and cover a range of world regions, biomes, and fire regimes. They are within the top impacted countries in terms of number of disasters, fatalities, people affected or total damage over the studied period according to the Emergency Events Database (Table S1; Section 2.2).

GT allows multiple topics to be queried simultaneously, with their RSIs provided relative to the topic with the highest total number of searches, which allows comparison of relative interest among different topics. Therefore, to compare the interest in wildfires versus other major natural hazards, data were mined from GT during the same study period and countries, including globally, comparing the topics "Drought", "Hurricane (= tropical cyclone)", "Earthquake", "Storm" and "Wildfire". This natural hazard comparison was done both at global and at country level including all countries, not only our five case study countries (results in Section 3.2).

In addition, overall RSI over time was compared to the relative search interests on the wildfire topic generated by using Google's advanced searches by images, news, or videos. This tool is only available for searches from January 2008 onwards (results in Section 3.3). Finally, GT also provides information regarding the most frequent types of queries related to a word, which we also obtained for wildfire searches at the global level (results in Section 3.4). This specific tool of GT does not allow looking by topic but rather by word. Therefore, once the wildfire query types were obtained, those not related to the topic, but to the word 'wildfire' in other contexts were manually removed (e.g. videogames, songs, Games of Thrones, etc.). Unlike the other GT tools used here, this particular one only covers search queries typed in the English language.

2.2. Fire occurrence and impacts data

Global and national (for the five case study countries) fire activity data were provided by the European Forest Fires Information System (EFFIS; https://effis.jrc.ec.europa.eu). Monthly area burnt for the globe, Australia, Canada, Indonesia, Portugal and the USA was derived from the MODIS burned area product MCD64A1, which identifies burned areas globally at a 500 m pixel spatial resolution (Artés et al., 2019). This information is available from the year 2002 onwards and therefore covers the whole study period.

Data on fire impacts (economic losses, number of people affected and number of deaths) was extracted from the Emergency Events Database (EM-DAT; Université catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium). EM-DAT provides open access data on the occurrence and impacts of over 22,000 natural and technological disasters, including wildfires, in the world from 1900 to the present day. The database is compiled from various sources, including UN agencies, non-governmental organisations, insurance companies, research institutes and press agencies. For an event to be included in EM-DAT it needs to fulfil one or more of the following four criteria: (i) 10 or more fatalities, (ii) 100 or more people affected (i.e. requiring immediate assistance during a period of emergency), (iii) declaration of a state of emergency or (iv) call for international assistance. It therefore does include key events, but not all damaging fire events, so lives lost and economic damage based on EM-DAT reported here are likely to be an underrepresentation of actual global values. Correlations between worldwide and country-level RSIs and these fire occurrence and impact indicators were performed (see Section 3.1.2).

2.3. Statistical Analysis of Google Trend Data

In order to examine the seasonal (i.e. months within each year) patterns of global interest in wildfires, time series decomposition was performed. This approach separates the time series into linear trend and seasonal components, as well as error and stochastic fluctuations (West, 1997). As the seasonal pattern in the data depended on the level of the data (i.e. more searches are likely to be carried out during months with active fires) a multiplicative model structure was employed accounting for this effect (Moustakas and Evans, 2016). A multiplicative detrending model was used when the size of the seasonal pattern in the data depended on the level of the data. The analysis resulted in four indices: seasonal indices, original data by season, percent variation by season, and residuals by season.

In addition, change point detection algorithms (Aminikhanghahi and Cook, 2017) were employed to detect changes in both the mean and variance of the global search interest in wildfires per month analysed as time series. The binary segmentation test statistic was used to detect changes in the data (Scott and Knott, 1974). The Bayesian Information Criterion was used for change point segmentation, with a maximum of 20 change points examined and a minimum segmentation length of 12 points (one year) for detecting a change point (Killick and Eckley, 2014). Change point detection methods allow the decomposition of complex non-stationary time series into segments where the mean and variance are constant, and thus such changes can be quantified (Aminikhanghahi and Cook, 2017).

Lastly, Spearman's rank correlation coefficients (r_s) were calculated to identify monotonic relationships between variables, using a level of significance of 5%. The following descriptors for associations based on the r_s values were used: very strong: > 0.8; strong: 0.8–0.6; moderate: 0.6–0.4; weak: 0.4–0.2; very weak-none: < 0.2.

3. Results and discussion

3.1. Temporal Trends of public interest in wildfires

3.1.1. Global trends

The global relative search interest (RSI) shows a low background level with frequent short-lasting spikes. The global temporal trend is highly cyclic (Fig. 1), mostly peaking every year between June and September, which are the months corresponding to the summer fire season in the northern hemisphere (Fig. 1 and Fig. S1). There are, however, notable exceptions to that pattern, which correspond to spikes related to wildfires that have happened outside of the northern hemisphere summer season. Most of these exceptions are catastrophic fires that have happened in California, for example in October 2007, October and December 2017, or October and November of 2018 (Fig. 1). There are also some peaks related to fires outside of the USA, for example, the Australian bushfires during the southern hemisphere summer (northern hemisphere winter) of 2019/2020 or the Fort McMurray (i.e. Horse River) wildfire in Canada in May 2016. Overall, however, events outside the USA seem to attract less global attention. For example, the Black Saturday fires in Australia in February-March 2009, which is the deadliest wildfire globally in recent history with 173 direct fatalities, resulted only in a minor spike in the global RSI. This also applies to the Pedrógão Grande wildfire in Portugal in June 2017, which caused 66 deaths but did not translate into a high global interest (28% RSI; Fig. 1).

In terms of temporal changes of wildfire search interest worldwide, four periods are identified (Fig. 1): a first period (Jan 2004 – Mar 2007) with an average RSI of 30% and relatively low variance, followed by a short period (Apr 2007 – Aug 2008) with higher RSI (average 37%), triggered mainly by an intense period of searches in Oct 2007 (coincident with catastrophic wildfires in California, see Fig. 1 legend). This was followed by a long period (Sep 2008 – May 2017) with the lowest worldwide RSI (average 24%), before a final period (Jun 2017 – Feb 2020) with both the greatest seasonal spikes and highest average RSI (41%). This increase in wildfire search interest during later years of the record is probably related to a higher occurrence of catastrophic events in several regions of the word, especially North America (see Section 3.1.2.; Iglesias et al., 2022). Indeed, there has been a several-fold global

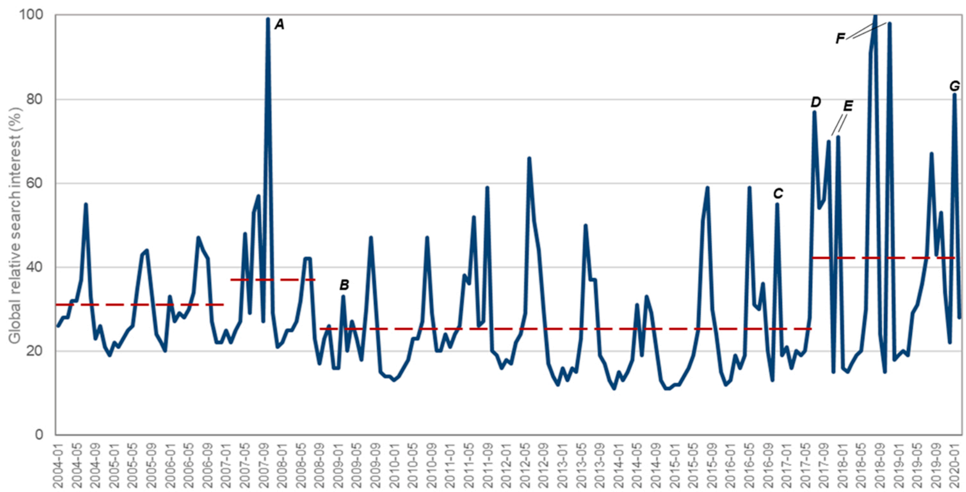

Fig. 1. Temporal evolution of the global relative search interest from Jan. 2004 to Feb. 2020. The dotted red lines show the means of the data within each of the four change-point segments identified. Capital letters A-G identify examples of spikes aligned with specific catastrophic fire events/seasons [A: Oct. 2007 California; B: Feb. 2009 Black Saturday Fires, Australia; C: Nov. 2016 the Great Smoky Mountains wildfires, Tennessee, USA (and Israel); D: Jul. 2017 British Columbia, Canada; E: Oct. and Dec. 2017 California (and Portugal in Oct.); F: Aug.-Nov. 2018, California; G: Jan. 2020 Australian Black Summer Bushfires].

increase in the insured losses from wildfires since 2017 (Bevere and Weigel, 2021).

To explore the relationship between global RSI and quantitative indicators of global wildfire activity and impacts, we compared the RSI trends to those for global area burnt, number of wildfire disasters, economic costs, number of people affected and number of deaths (see Section 2.2 for details). Only moderate to weak correlations were found between global RSI and these variables (see Fig. 2 and Tables S2).

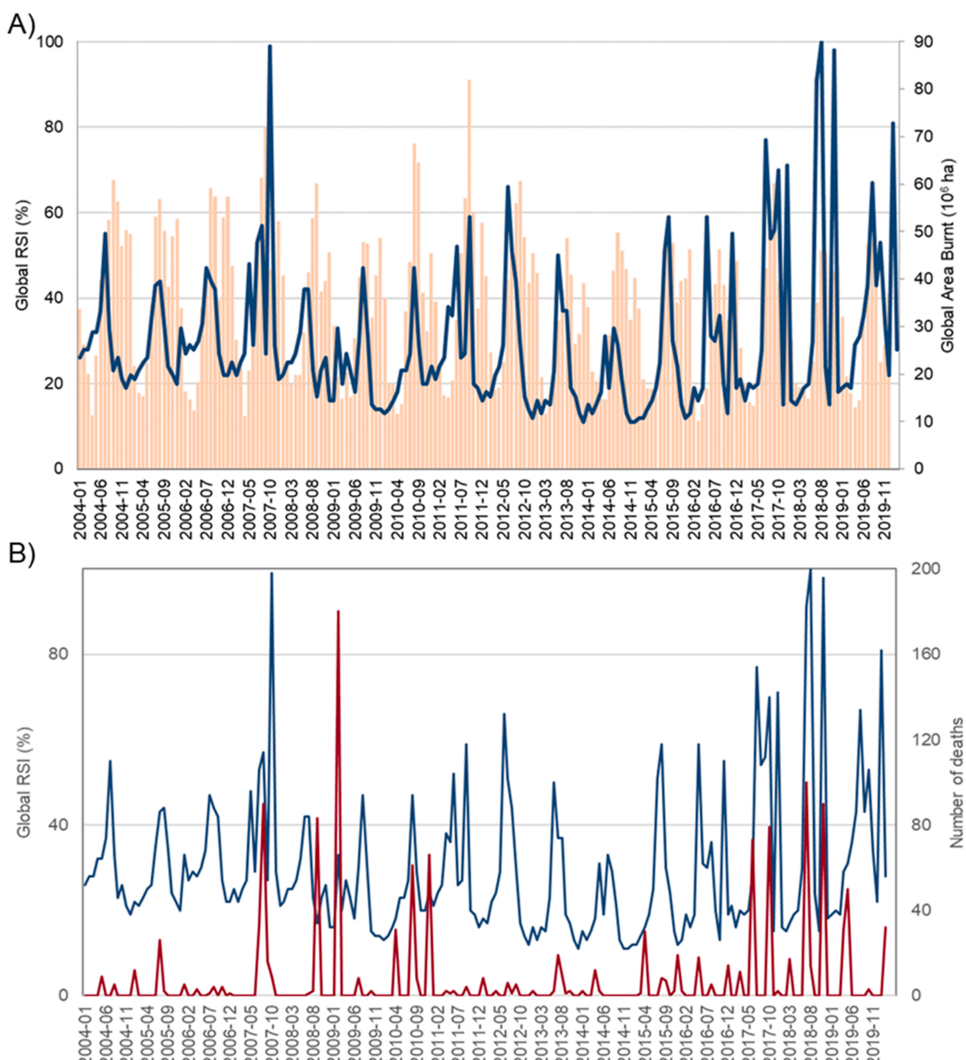

Fig. 2. Temporal evolution of global relative search interest (blue line, left Y axis) compared to: A) global area burnt (red bars, right Y axis); and. B) global total deaths from wildfires (red line, right Y axis). For specific timing of key fire events see letters in Fig. 1.

Burnt area is a widely used parameter to describe trends and patterns in fire activity (e.g. Andela et al., 2017); however, only a weak correlation was observed between global area burnt and public interest (Fig. 2A and Table S3). This is not surprising as a substantial fraction of the area burnt worldwide every year is in remote or sparsely populated regions (e.g., tropical savannas or boreal forests; Jones et al., 2022). These fires are rarely picked up by the media or draw widespread public attention, as they do not usually lead to substantial impacts on humans and/or assets (Doerr and Santin, 2016).

Global search interest did show somewhat stronger relationships with the descriptors of wildfires impacts on humans studied here, although only ranging from weakly to moderately correlated (i.e. number of wildfire disasters (r_s: 0.44) > number of people affected (r_s: 0.37) > economic damage (r_s: 0.32) > number of deaths (r_s: 0.30); Fig. 2B and Table S3). The lack of stronger correlations may be, at least in part, due to the fact that global RSI is not spread equally around the globe, due to lower internet penetration (i.e. portion of the population that has access to the Internet) in less developed countries (Pew Research Center, 2019). Moreover, not all catastrophic events receive the same amount of global interest. For example, for other natural hazards (earthquakes), it has been demonstrated that overall global interest is higher when they occur in developed countries than in developing countries (Kam et al., 2021).

3.1.2. *Trends by country*

In addition to global trends, the temporal evolution of RSI was examined for five selected case study countries: Australia, Canada, Indonesia, Portugal and the USA. This selection covers a wide geographical range, and all these countries present high fire activity and have been affected by catastrophic wildfire events in the study period. All five countries present a similar pattern to that observed for the global RSI, with a low background level of interest with intermittent spikes of high RSI (Fig. 3). These temporal spikes in interest, however, vary greatly between the case study countries, with very few spikes occurring at the same time across several countries. This points to each country-level RSI being driven mostly by national events (see Fig. 3 caption).

For most of the case study countries, the background level of interest is lower (in the region of 5–15% except for Indonesia; Fig. 3) than for the global RSI (in the region of 20%; Fig. 1). The same is true for the average RSI for the studied period (Global 29%, Australia 13%, Canada 7%, Indonesia 22%, Portugal 11% and the USA 19%). This indicates that global RSI is driven by multiple countries and, therefore, by fire seasons and events that do not overlap in time. It is notable that the highest RSI for the five studied countries occurred within the last four years (Fig. 3), the period identified as having the highest global average RSI (see Section 3.1.1). The case of Canada is especially relevant as it had a very low RSI over the first ten years of the study period (2004–2013), but search interest grew markedly in the last 5–6 fire seasons. This aligns with an observed climate-change influenced increase in fire activity and associated impacts in Canada and other forest dominated boreal and temperate regions (e.g. British Columbia fire seasons of 2017 and 2018; 2016 Fort McMurray wildfire; 2017 Portugal Wildfires, Turco et al., 2019; Kirchmeier-Young et al., 2019; 2019-2020 Black Summer in Australia; Canadell et al., 2021).

When comparing the global with the country-level RSI temporal patterns, the closest similarity is shown by the USA with most spikes in interest there matching those found at global level. This close association does not apply so clearly to the other four countries studied (i.e. Australia, Canada, Indonesia and Portugal) (Sup. Fig. S2). Correlations between global and country-level RSIs corroborate this, with the correlation between global and USA RSIs being the strongest (Table S2). This may be due in part to some USA fires sparking interest both at USA and global levels but not in the other four countries studied. Conversely, in the cases of Australia, Indonesia and Portugal, there were local events leading to RSI spikes in those countries but not at the global level (Sup. Fig. S2). Some examples of those are the already mentioned 2009 Black Saturday bushfires in Australia, the Iberian wildfires in Portugal in October 2017 or the 2006, 2015 and 2019 Southeast Asian haze seasons triggered by wildfires in Indonesia (Fig. 3). Regarding Canada, major fire events here seem to trigger a global response even when these events do not trigger such a strong response in the USA (Sup. Fig. S2). The relatively higher global interest in catastrophic Canadian fires over those in Australia, Indonesia or Portugal is challenging to explain. It could be due to a mix of a "developed country bias" (i.e. disasters in countries with higher GDP per capita attract more public attention; Habibi and Feld, 2018) and, also, due to "distance bias" (the likelihood that a disaster is covered by the media depends on the distance between the country where the media are located and the country where the disasters occur; Berlemann and Thomas, 2019). This would mostly affect the interest from the public in the USA (note that USA and Canada RSIs are strongly correlated, Table S2). Another contributing factor might be a bias in the GT method, if English speaking searches were somehow better identified than those performed in other languages. However, the search by 'topic' instead of by word should in principle overcome this limitation (see Section 2.1). Moreover, this possible bias does not address the fact that some of the main wildfire disasters in Australia, also a dominant English-speaking country, are not reflected in the global RSI. Another possibility is a methodological bias toward the word 'wildfire' (widely used in North America) compared to other synonyms (e.g. bushfire, commonly used in Australia). Unfortunately, GT algorithms are not public and, therefore, it is not possible to corroborate or refute these methodological bias hypotheses.

We also explored potential associations between RSI and area burnt at the national levels (Table S2). In contrast to what is observed at the global level, strong correlations were found at the country level for Canada (r_s: 0.72), USA (r_s: 0.61), and Portugal (r_s: 0.61). For Indonesia, this correlation was only weak (r_s: 0.38). An issue of particular concern relating to wildfires in Indonesia is smoke pollution. This is caused by

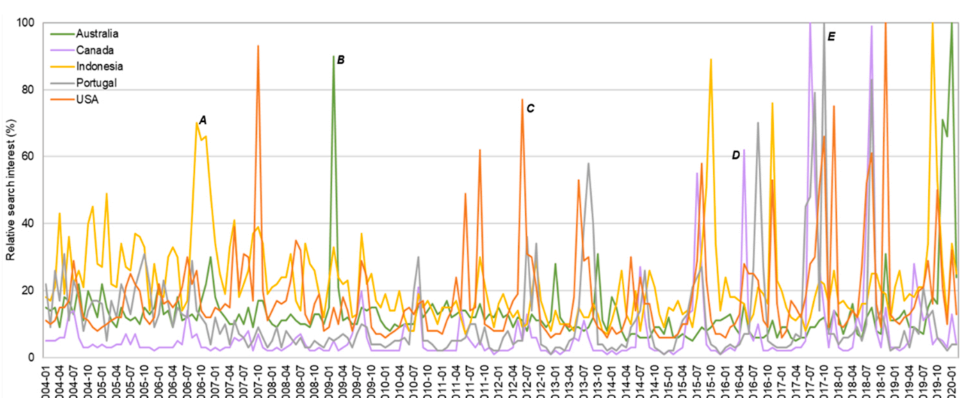

Fig. 3. Temporal evolution of the relative search interest from Jan. 2004 to Feb. 2020 for the five case study countries. A-E identify fire events aligned with spikes of RSI at national level, but not in other countries or at global level [A: Aug.-Nov. 2006 Indonesian fires, B: Feb. 2009 Australian Black Saturday fires; C: Jun. 2012 Colorado wildfires, USA; D: May 2016, Fort McMurray fire, Canada; E: Oct. 2017, Iberian wildfires, Portugal]. See Fig. S2 for more explicit representation of each country and comparison to global data.

fires in peatlands, which may not affect extensive areas, but burn deep into organic soils for long periods of time (Field et al., 2016; Sastry, 2002). Interestingly, no correlation between area burnt and national RSI was found for Australia, which may be attributed to the fact that area burned here is dominated by frequent burning of savanna grasslands in northern Australia, rather than the more destructive forest fires of south-eastern and south-western Australia (Russell-Smith et al., 2007). These grassland fires have little direct impact on human populations and are thus not particularly newsworthy (Doerr and Santin, 2016).

3.2. Comparisons with other natural hazards

To evaluate the search interest in wildfires within the broader context of natural hazards, global RSI for wildfire was compared to that of four other globally relevant natural hazards: earthquakes, hurricanes, storms, and droughts. The most searched natural hazards at the global level are earthquakes and hurricanes, followed, to a lesser extent by storms, and then by droughts and wildfires (Fig. 4). When comparing global temporal trends over the last 16 years, the low RSI for drought and wildfire compared to the other natural hazards (always <3%; Fig. 4) makes identifying peaks and patterns challenging. For hurricanes, earthquakes and storms, their RSI follow more distinct patterns. Hurricanes, which have the highest RSI, present a cyclic pattern, similar to the one observed for wildfires (Section 3.1). The background level is very low outside of the Atlantic hurricane season (<5%: Fig. 4), which typically falls between August and November, peaking in September. Furthermore, the South Pacific cyclone season (November - April) is not reflected at all. The global interest seems to be predominantly driven by catastrophic hurricanes affecting the USA, such as Hurricanes Ivan (2004), Katrina (2005) and Harvey (2017) (Fig. 4). For example, the Typhoon Haiyan (Nov. 2013), one of the worst tropical cyclones in Southeast Asia, with around 6300 deaths, did not translate into a major spike in the global RSI. For earthquakes, the RSI background level is higher than for hurricanes, with no seasonal spikes, which is expected given that earthquakes do not fall into a specific season. In contrast to hurricanes, the interest in earthquakes is driven by catastrophic events all around the world (Fig. 4). Regarding storms, spikes are not as pronounced as for hurricanes and earthquakes (Fig. 4). This may be because, in the global context, storms are more widespread events both geographically and throughout the year compared to some of the other natural hazards studied. They are also more frequent and generally not as damaging per individual event as hurricanes or earthquakes. It is, however, notable that there has been an increase in RSI for storms over time (Fig. 4), which may be associated to recent increases in heavy precipitation over many regions worldwide, related to human-induced climate change (Douville et al., 2021).

The relatively low public search interest in wildfire compared to earthquakes and hurricanes may be related to the fact that the socio-economic impacts of the latter are usually higher. For example, the costliest wildfire disaster in history, the Camp Fire (USA, Aug. 2018; Peak F in Fig. 1), had $17 billion associated losses (Munich Re, 2018), whereas the costliest hurricanes have been Hurricanes Harvey (USA, Aug. 2017) and Katrina (USA, Aug. 2005) with $125 billion losses each (NOAA, 2018). The costliest earthquake in history by far has been the Tōhoku Earthquake and Tsunami (Japan, March 2011) with $198–309 billion estimated losses (Mimura et al., 2011).

The natural hazard comparison was also done at the country level (for all countries, not only our five case study countries; see Methods in Section 2.1). No country has wildfire as the top natural hazard in their Google searches (Table 1). Search interest for wildfire is low when compared to the other four natural hazards studied, with wildfire RSI always less than a third of the RSI value attributed to the most searched natural hazard in each country. Canada has the highest RSI for wildfire when compared to the other natural hazards studied here (31%; Table 1), which matches the fact that the 2016 Fort McMurray wildfire has been the costliest disaster in Canada to date (Tymstra et al., 2020). The second highest is Finland, followed by Portugal, Sweden and Germany (26–20%; Table 1). The relative interest about wildfires in countries with relatively low fire activity, like Finland, Sweden or Germany, may be related to the fact that the other natural hazards considered here are not very common in these countries either. In addition, the fact that these countries have experienced some severe fire seasons over recent

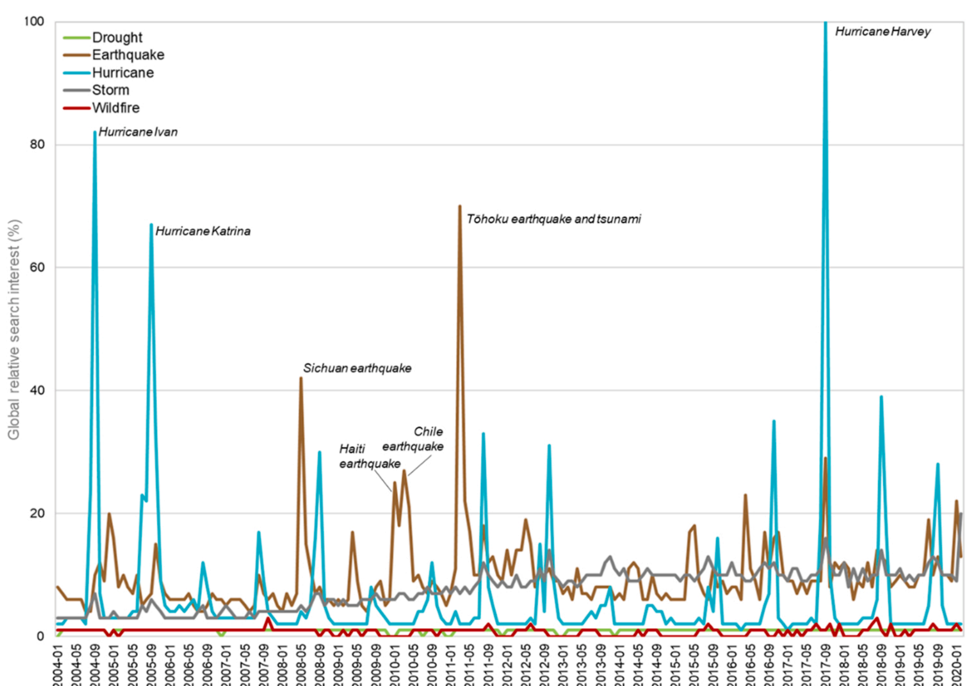

Fig. 4. Temporal evolution at the global level of the relative search interest for the five natural hazards studied from 01/2004–02/2020. Catastrophic events that align with major RSI peaks are identified. For hurricanes, several hurricanes may have happened around a specific date but only the name of the costliest one is shown here.

Table 1
Relative Search Interest per country for the five natural hazards studied between Jan. 2004 and Feb. 2020. Note that for each country, the RSI values are relative (in %) to the natural hazard with the highest search interest. For a full list of countries, including low-search countries, see Table S4. *Case study countries in this study.

	% Relative Search Interest				
	Wildfire	Drought	Hurricane	Earthquake	Storm
Canada*	31	6	100	69	72
Finland	26	19	84	94	100
Portugal*	25	84	56	100	47
Sweden	20	48	23	60	100
Germany	20	10	22	93	100
Netherlands	18	8	58	68	100
Austria	16	7	18	100	86
Indonesia*	14	6	3	100	17
Belgium	14	14	62	81	100
Denmark	13	9	27	73	100
Hong Kong	12	5	83	100	44
South Korea	11	7	18	91	100
Thailand	10	10	10	73	100
Switzerland	10	8	32	100	50
Australia*	9	18	82	100	94
Malaysia	9	4	35	100	70
United Kingdom	9	6	86	86	100
Spain	8	6	39	100	51
United States*	8	4	100	48	40
Singapore	7	4	51	100	60
Norway	3	7	7	16	100
Ecuador	2	1	8	100	8
Philippines	2	2	100	85	28
New Zealand	1	1	18	100	15
China	1	4	1	100	23
Chile	1	1	4	100	6
Turkey	1	0	2	100	5

years, against a background of a historically limited fire occurrence, may also play a role (e.g. 2006 and 2018 in Finland; 2018 and 2019 in Germany; 2014 and 2018 in Sweden; Fernandez-Anez et al., 2021; San-Miguel-Ayanz et al., 2022).

3.3. *Comparison of general web searches with specific news, image or video searches*

The temporal evolution of the global RSI via general Google searches was compared to specific Google searches for images, news and videos. In general, these specific searches followed similar trends although they do not always match closely (Fig. 5). For example, the spike in news and video searches in June-July 2008 was probably related to the 2008 Californian wildfires, but these fires did not generate a lot of general Google search interest. Similarly, one of the highest proportions of video searches occurred in August 2019, probably associated with fires in the Arctic, but this period exhibits only a modest interest via general, news and image searches. The Australian 2019/20 bushfire season aligned with very high Google RSI and the highest spike in video searches with, for example, one video showing a woman washing the burnt hands of a kangaroo attracting over 15 million views (https://www.youtube.com/watch?v=KZa05ixGs1g). However, that period did not result in such a high proportion of news searches. On the other hand, there have been wildfire seasons that have driven a very high Google RSI, such as the Californian season of 2018, but have not generated such a high volume of news, video or image searches (Fig. 5).

When examining the correlations among the different types of Google searches, we found that the strongest association occurs between general searches and news searches (Table S5), highlighting how public interest is linked with a demand or supply in news on this topic. The weaker correlations of general searches with searches for images and videos could indicate that people searching for the topic may be either fundamentally more interested in written information than in visual impressions or, simply, that in those instances there are no especially captivating images or videos that went viral.

3.4. *What drives public interest?*

In total, 160 query types related to the wildfire topic were identified (Table S6). The majority of them (56%) were related to the understanding of wildfire functioning. For example, where wildfires start, how they spread, why they happen or how they can be prevented. A smaller proportion (13%) were queries related to impacts on health, mostly related to questions about effects of smoke, such as 'why smoke is bad' or 'whether it can make you nauseous'. Other types of wildfire impacts were also searched for, mostly regarding environmental effects (9%). For example, 'what impacts wildfires can have on ecosystems' or 'what is the relationship of wildfire with water quality or climate change' (Table S6). A small number of query types (3%) were related to other matters such as 'what to do during a wildfire' or 'when to evacuate'. It is worth highlighting that a large proportion of all query types (39%) are about specific fire events, locations or periods of time, with around half of those being exclusively about these matters (e.g. 'wildfires near me today') and the other half related to the functioning type of questions highlighted above (e.g. 'why wildfires happened in Australia in 2019'; Table S6).

In terms of the specific words used for wildfire-related Google searches, the world cloud in Fig. 6 displays those found in the query types identified. The most common words in descending order were smoke > cause > season > California > start > Australia = happen = occur. This supports the idea that the public interest is focused on functioning of fire (e.g. 'cause', 'start', 'happen'), its health impacts (e.g. 'smoke') and specific locations with relatively frequent catastrophic fires (e.g. 'California', 'Australia'). It is important to note that the list of the most frequent queries related to wildfires contains no information about the specific frequency or total number of each of these. Therefore, the

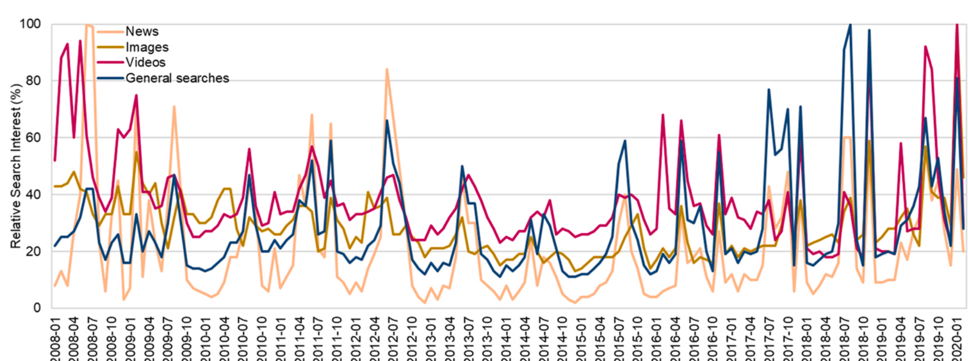

Fig. 5. Temporal evolution at the global level of the relative search interest for general Google searches, and specific Google searches for images, videos and news within the wildfire topic, from Jan. 2008 to Feb. 2020.

Fig. 6. Word cloud generated using the 108 key words identified in the 160 query-types in the English language. Word sizes in the cloud are relative to the frequency each word was in the query dataset.

sizes of words in Fig. 6 are related to the number of queries they appear in among the total of 160 identified. They are not measurements of the number of Google searches with that specific word. It is also important to point out that this information, extracted from the GT tool, only provides information on queries in English, and only for the word "wildfire" (i.e. it does not include synonyms or other languages as the other GT tools used in this study (see Section 2.1)). Hence, the information provided comes exclusively from English-speaking users, who will be most likely based in English-speaking countries. Notwithstanding this, these specific results show that the public uses the internet to obtain basic knowledge about wildfire functioning/occurrence and their impacts and, specifically, further information on wildfires near to them.

3.5. Limitations

GT is increasingly used to gather information about the public's interest in a range of topics, including environmental conservation and natural hazards (Anderegg and Goldsmith, 2014; Andrew et al., 2016; Habibi and Feld, 2018; Kam et al., 2021; Kovalenko et al., 2021). It is a free-access tool with a spatial and temporal reach that is much broader than traditional surveying methods; however, it also comes with limitations, which are important to consider when drawing conclusions from its outputs.

Internet penetration varies among countries and individuals, with higher use in more developed countries. In addition, younger users, those with higher education levels, and/or higher income have a higher probability of using the Internet (Pew Research Center, 2019). Therefore, the global data here is biased towards more developed countries. Notwithstanding this, the reach of the internet has increased dramatically during our study period, from 17% of the world population in 2006 to 57% in 2019 (The World Bank, 2020). Its user profile has thus become more representative of the global population.

The fact that GT provides data from internet searches only from Google as a search engine is also a limitation, although only a minor one given that Google is the most used web search engine in the world, with around two trillion searches per day (Arora et al., 2019). We can thus expect a good global representativeness except for internet-censored countries impacted by website filtering and/or promotion of alternative search engines, such as in the case of China.

In addition, it has been suggested that, as internet users and search volumes increase over time, trends detected with this tool might be caused by both genuine variation of search volume for the studied topic but also by variation of search patterns in other unrelated fields (e.g. decreases of searches for a given topic due to increases of searches for other topics) (Ficetola, 2013). The use of unrelated terms as benchmark have been suggested to identify trends that are not genuine, but we argue here that benchmark terms are not needed as GT normalizes and scales the search volume data, reporting already scaled rankings of percentages (McCallum and Bury, 2014).

Regarding the sampling method, GT data are generated from a sample of searches made by users that Google describes as "random" and "unbiased". Cebrián and Domenech (2022) demonstrated that GT data are robust in terms of completeness, consistency, and validity, but they found an issue in terms of accuracy, as the same queries do not always provide the exact same results. This sampling error cannot be quantified, as sampling methods are not disclosed by Google. However, Cebrián and Domenech (2022) also found that the different time series generated are highly correlated and, therefore, this accuracy issue is not expected to substantially affect the type of analyses performed in the current study. In addition, the use of 'topic' in the current study instead of 'key word' should in principle avoid bias in terms of language or location (see Methods 2.1), but we cannot rule out that there may be some, unfortunately unquantifiable, bias toward searches happening in North America, as shown not only for wildfires (Section 3.1.2) but for other natural hazards (Section 3.2). This potential North American bias may be due to a shortcoming in the GT data mining processes but it could also, or alternatively, be due to an uneven production and circulation of news and other online content of events happening in North America compared to those in other regions or countries. In this regard, there is long-term evidence of USA's dominance in the international news (Segev and Blondheim, 2013).

Lastly, it is clear that GT data mining cannot be seen as a substitute for traditional surveys or questionnaires, as the type of information gathered does not provide in-depth knowledge on, for example, the motivation for the internet searches. In this sense, future research combining and comparing both types of methods could be designed with the aim of gaining a comprehensive understanding of what really motivates the surge in search interest during/after a catastrophic wildfire (or other events of interest), and with the potential to compare the results both at the region/country where the event occurred and with other regions/countries.

4. Conclusions and implications for society, wildfire policy and management

To the authors' knowledge, this is the first study that has quantitatively examined the public's interest in wildfire at the global level and it demonstrates that, in terms of internet searches, public interest in wildfires is on the rise. The rate of interest is not steady, but follows a cyclic pattern with much higher interest during the northern hemisphere summer (i.e. its dominant wildfire season) and with the greatest interest spikes concomitant with specific catastrophic wildfire events or seasons. Therefore, the marked increase in interest over the last few years (since 2017) is probably linked to the particularly high number of catastrophic wildfires that occurred around the world in this period, with many of these events affecting densely populated areas in developed countries and resulting in substantial socioeconomic impacts (Bevere and Weigel, 2021; Iglesias et al., 2022; United Nations Environment Programme, 2022).

This pattern of a relatively low background interest with spikes around the period of a catastrophic event is also found for other natural hazards. Previous studies have shown that public concern is often very high in the aftermath of a disaster, but it tends to decline and fade away over time (Anderegg and Goldsmith, 2014; Mondino et al., 2020). Public interest is critical in affecting public policy and actions (Mccallum and Bury, 2013) and thus we argue here that its cyclic pattern presents a key obstacle to more adaptive policies on disaster mitigation and management. This is especially acute for wildfires, as not only their impacts but also their extent and severity can be effectively reduced by all year-round awareness and mitigation actions (Cochrane and Bowman, 2021; Doerr and Santin, 2016; Moritz et al., 2014). Fuel reduction burns, for example, are a proven tool for reducing fire risk but they require public support due to their cost, smoke emissions and perceived ecological impacts. They can only be performed during periods of low fire risk (i.e. usually outside of the main fire season), which are periods in which interest in fires wanes. On the other hand, suppression activities take place during the period with peak public attention, which may help explaining why those are still the strongest focus of resource allocation and associated policies, even though it is well known that off-season mitigation strategies are more effective and resource-efficient (Moore, 2019; Tedim et al., 2020).

Recognising this challenge, the knowledge of cyclic interest can be harnessed in terms of policy and management, for example, by carrying out specific awareness campaigns, or implementing a regulatory change towards safer building standards during periods when the population is more interested in the subject. Indeed, previous research has shown that extreme natural events can create opportunities for policy actions to address environmental problems usually neglected (Farhidi et al., 2022). Furthermore, the 'high awareness' periods can be a window of opportunity in cases where disasters affect a developing country and humanitarian aid may be needed (Kam et al., 2021).

In addition, our finding that a substantial proportion of the search queries on wildfires are related to wildfire occurrence, functioning and their impacts suggest that there is a demand for educational information by the public. This demand, especially during 'interest spikes', could facilitate dissemination of information about wildfires and even about broader related environmental issues. Previous studies focusing on other natural hazards have found that public interest is more focused on more infrequent and more sensational hazards than in the most common and distributed ones (Houser et al., 2019). Environmental issues that tend to get more media attention are those which have immediate and drastic consequences. This is why climate change is so challenging to report on, as its impacts mostly occur over long-time scales which do not fit within the fast-paced media environment (Hopke, 2020). Considering this, catastrophic wildfire events could be utilized to educate the public about climate change and its environmental and socioeconomic consequences. Indeed, there is already an increasing trend of news reporting on wildfires that also discuss the role of climate change in them (Hopke, 2020).

Our results further indicate that most of the catastrophic fires that drive the global interest occur in Western countries and, especially, in the USA. This matches the fact that USA has by far the greatest proportion of insured losses from wildfires (Bevere and Weigel, 2021) and, also, the long-proven predominance of USA in international news (Segev and Blondheim, 2013). Similar findings have been identified for other natural hazards. Kam et al. (2021) reported that the global community shows a higher level of interest when an earthquake occurs in developed countries than in developing countries. This bias can hinder international responses to disasters in other regions of the world as it can overlook important events. This was the case, for example, for the wildfires in Algeria in the summer of 2021, which caused over 90 deaths but went mostly unnoticed by the world (Bento-Gonçalves, 2021). It may also be that the GT algorithms are somehow biased towards internet searches in North America (Section 3.5). Previous studies do not mention this potential bias and Google does not provide any information that would enable exploring this possibility, but we suggest that this warrants further investigation in future studies.

We also show a strong link between general public interest and searches for news on wildfire. Public interest often increases as traditional mass media and social media report disasters and spread the information 'regarding the pain of others' (Moeller, 2006). Therefore, disaster journalism is often more focused on the subjective emotional and storytelling aspects of the catastrophes than in reporting more objective and quantitative information, such as the number of deaths and economic losses (Cottle, 2013). In addition, wildfires are sometimes portrayed as a 'spectacle'. This is a serious obstacle to the promotion of coherent risk governance and social learning, which involves recognizing wildfire risk as a social, political, economic, and environmental issue (Silva et al., 2019). On the other hand, media are integral to the 'cultural politics of the environment', and they are, therefore, key in the social construction of climate risk (Hopke, 2020). We believe the research community has a duty towards this very pressing issue. When journalists and researchers work together, the information that reaches the public is more credible, scientifically-sound and nuanced (Smit et al., 2022). Fluid communication between fire research and the media is therefore essential to send the correct messages to society.

Funding

This work was supported by the European Cooperation in Science and Technology (FIRElinks COST Action grant no. CA18135). C. S. received funding from the European Union's Horizon 2020 Research and Innovation Programme under the Marie Skłodowska-Curie Grant Agreement 663830 and the Spanish 'Ramon y Cajal' programme, Ref. N. RYC2018–025797-I. S.D. was supported by the H2020 grant FirEUrisk, Ref. 101003890.

CRediT authorship contribution statement

Cristina Santín: Conceptualization, Formal analysis, Writing – original draft, Funding acquisition. **Aristides Moustakas:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Funding acquisition. **Stefan H. Doerr:** Conceptualization, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

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

Data Availability

Data will be made available on request.

Acknowledgments

Special thanks to EFFIS (Jesus San Miguel, Duarte Oom and Pieralberto Maianti) for providing us with the fire activity data. We also thank Gareth Clay (Manchester University) for proof-reading of the revised version of the manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2023.05.008.

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