Characterizing Fire Behavior Across the Globe

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Abstract—Wildfire environmental impacts and the threat they pose to human live and values depend of how fast it spreads, how much biomass is consumed, and how much energy it releases and at what rate. Nearly every feature of contemporary fire management relies upon the understanding and prediction of fire behavior characteristics and a number of tools have been developed for such purpose. However, no attempts have been made so far to provide an overall worldwide picture of fire behavior characteristics, patterns and drivers. These are the general objectives of the BONFIRE project, requiring compilation of the available fire behavior information from field experimental fires, wildfires, and prescribed fires in a global database and subsequent integrated analysis of variation in fire behavior characteristics. We describe the methodology used to build the database, examine data partition by country, climate, biome and fuel complex categories, and mention the difficulties inherent to the process.

Keywords: wildland fire, experimental burning, fire modeling, pyromes, fire-climate relationships

INTRODUCTION

The environmental effects (on ecosystems, geosystems and the atmosphere) and societal impacts of any given fire depend on how fast it spreads, how much biomass it consumes, and how much energy it releases and at what rate (Albini 1984; Reinhardt et al. 2001). These are fire behavior attributes, and are determined by the fire environment, i.e. the combined influences of fuel (burnable vegetation) structure, topography, atmospheric weather, and drought (Countryman 1972). Nearly every feature of contemporary fire management, from fire prevention and fire control operations to the appraisal of its ecological effects relies upon the understanding and prediction of fire behavior characteristics (Scott et al. 2014). This has prompted the development of models capable of predicting with reasonably accuracy the most relevant fire behavior characteristics, namely rate of spread and flame size.

Data from outdoors experiments and other sources resulted in fire behavior models and fire danger rating systems specific to various vegetation types in Australia, Canada, and Europe (e.g., Anderson et al. 2015; Cheney et al. 1998, 2012; Cruz et al. 2005; Fernandes et al. 2009; Forestry Canada Fire Danger Group 1992). These models are empirically based i.e., the dependent variables are statistically related to environmental variables, but can perform acceptably outside the range of observed conditions if the embedded relationships are robust enough (Cruz and Alexander 2013). A distinct approach has been pursued in the U.S.A., resulting in a semi-empirical fire

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spread model usable in any vegetation type provided that its fuel properties are described as a fuel model (Rothermel 1972). However, attaining satisfactory predictions depends on whether the fuel models have been calibrated with observed fire behavior data or not (Ascoli et al. 2015; Cruz and Fernandes 2008; Hough and Albini 1978).

Wildland fire science has been expanded to analyze fire activity and effects at the global scale, including fire-climate interactions and the contribution to carbon emissions (e.g., Archibald et al. 2013; Moritz et al. 2012; van der Werf et al. 2010). Uncertainty in large-scale estimates of fuel consumption and carbon release by fire persists because of the importance of site-specific influences (Kasischke and Hoy 2008). In fact, sufficiently accurate fire behavior prediction for operational and management purposes is currently limited to specific vegetation types (Cruz and Alexander 2013). The incomplete understanding of global fire behavior patterns and drivers is an important knowledge gap that constrains: (1) adequate prediction of fire activity at different temporal and spatial scales; (2) foreseeing the response of fire activity to global change; and (3) formulating and enacting fire management policies to cope with fire regime changes.

This paper introduces the BONFIRE project, which intends to provide an overall worldwide picture of fire behavior patterns and drivers. Achieving these goals requires compiling the extant fire behavior data in a global database. Here, we describe the data acquisition process and first results.

DATA COLLECTION METHODS

The BONFIRE fire behavior database is being established by collecting information from various sources, namely the peer-reviewed literature, technical reports and grey literature (often addressing wildfire case studies), online databases (http://www.fbkb.ca; https://www.fs.usda.gov/rds/archive/), and unpublished data. Whenever the actual data was unavailable in the publications the respective authors were contacted and asked to share it. Data originates from outdoors fires in natural or activity (slash and masticated) fuels, the former comprising both flaming and smoldering (peat) fires. We restricted data collection to headfires spreading in the absence of interaction between fire fronts. When multiple observation periods were available, wildfire data collection was limited to the period of maximum rate of spread in a given vegetation type.

Ancillary data for each fire observation comprised the respective literature reference, country, location (name and geographic coordinates), observation type (experimental fire, prescribed fire, wildfire), Koppen-Geiger climate classification (Peel et al. 2007), mean annual temperature and rainfall (1970-2000) from the WorldClim 2 database (Fick and Hijmans 2017), biome and ecoregion (Olson et al. 2001), NCAR LSM surface type (e.g. cool broadleaved deciduous forest) (Bonan 1996), generic vegetation type (i.e., forest, woodland, shrubland, or grassland), and dominant species.

Fire behaviour was described in terms of:

1. Type of fire type, i.e., surface, intermittent or passive crowning, or active crowning.
2. Characteristics of the forward section of the fire front, i.e., rate of spread, flame characteristics (height, length, tilt angle), and Byram's fireline intensity.
3. Fuel consumption (absolute and relative) by fuel layer, size class, or condition (dead or live), supplementing a previous database (van Leeuwen et al. 2014) but retaining only those fires for which fuel moisture contents were known.

Additional fire characteristics (flame depth, flame residence time, combustion time) were seldom available and were not included in the database.

The corresponding fire environment was described through:

1. Terrain slope.
2. Atmospheric conditions, i.e., wind speed, relative humidity, and air temperature.
3. Fuel moisture contents by fuel layer, size class or condition, or its Canadian Forest Fire Weather Index System (Van Wagner 1987) surrogates (Fine Fuel Moisture Code, Duff Moisture Code, Drought Code).

4. Nature of the surface fuel complex (litter, grass, shrub, moss-lichen, slash, masticated, and their combinations), and whichever fuel characteristics were available, namely height and cover percent by fuel layer, fuel loads (by layer, size class, or condition), dead fuel percent, curing percent, and forest canopy fuel descriptors (height to live crown base, canopy bulk density).

Each fire entry was assigned an ignition mode (point or line), ignition line length or fire width, and reliability scores (Cheney et al. 2012) for fire behavior characteristics and weather and fuel conditions.

DATA COLLECTION RESULTS

As of the end of May 2018, the BONFIRE database includes about 6000 individual entries from 33 countries, of which three-quarters constitute experimental fires. As expected, countries with long-standing wildland fire research histories and established fire management policies and practices contributed a disproportionately amount to the database, namely Australia (25.6% of the total number of records), USA (17.2%), and Canada (8.1%); South Africa is also well represented (21.1%), however, most of its data comes from the Kruger National Park long-term fire ecology research program (Biggs et al. 2003). The location map (fig. 1) highlights the concentration of experimental fire and wildfire sites in North America, temperate Australasia, and southwestern Europe. Note the scarcity of locations in Russia, Asia and the other regions of Africa and, to a lesser degree, central and South America.

Fully humid warm temperate climates (Cfa, Cfb) accounted for 28.9 percent of the observations, closely followed¬25.7 percent of observations– by warm temperate climates with a dry summer (Csa, Csb) or a dry winter (Cwa). The hot steppe/desert variant of steppe climates (Bsh) ranked next (18.7%), with fully humid snow climates (Dfc, Dfb) and dry-winter equatorial savannah (Aw) being also relevant, respectively 12.1 and 5.0 percent of the observations. Four biomes dominate the database, respectively tropical and subtropical open vegetation types (30.0%), temperate broadleaf and mixed forests (25.7%), temperate conifers (13.7%), and Mediterranean forests, woodlands, and scrub (13.2%), but boreal forests (5.0%) and temperate open types (4.9%) are also relevant. In regards to vegetation

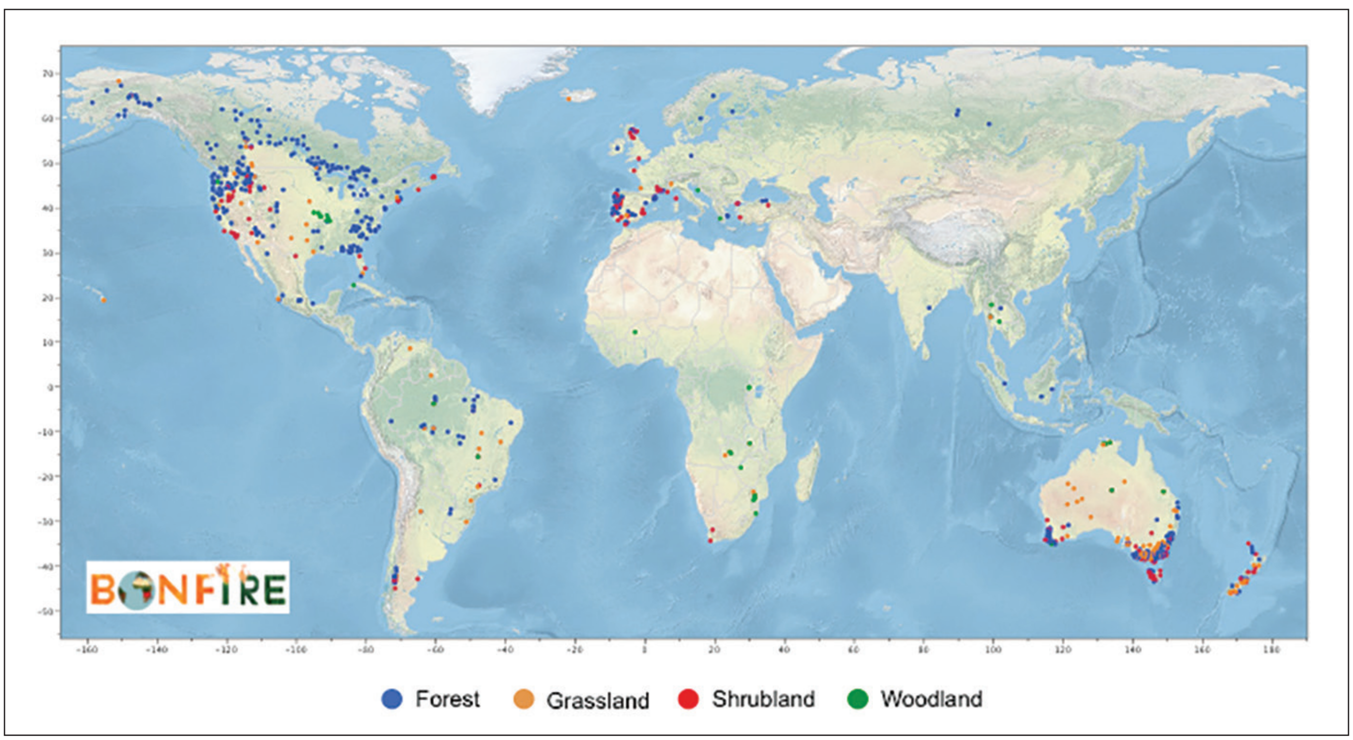

Figure 1—BONFIRE database locations by generic vegetation type as of the end of May 2018.

type, the number of observations decreased in the forest–grassland–shrubland–woodland direction, with respective shares of 44.4, 25.2, 17.5, and 12.8 percent.

The surface fuel complex is either made up of grass or dominated by grass in 50.6 percent of the cases. Litter-dominated fuel complexes rank next (23.9%), followed by shrubs (11.0%), slash alone or in combination with other types (8.5%), and dominance by mosses and/or lichens (4.8%). Table 1 additionally emphasizes the ubiquity of grass-dominated fuel complexes, while dominance by litter or shrubs is more represented in temperate and Mediterranean climates.

A number of issues and difficulties became readily apparent during the process of compiling and organizing the database, starting by uneven data collection and reporting. Field methods are understandably highly variable, as they reflect each study context and objectives, which has impacts on datasets comparability and the completeness of the description of the fire environment variables. For example, wind speed measurements can take place within the 1.2-2 m height range or at a height of 6 or 10 m in the open. The metrics used to describe the fuel complex vary widely, from qualitative descriptions (e.g. fuel type), to fuel hazard scores, to thorough quantitative assessments of fuel structure and load that distinguish between fuel layers, size classes, and dead or live condition. Similarly, fuel moisture and fuel consumption can be available for just the fine dead fuels that often drive fire spread or be detailed by categories, as defined by layer, size, and condition.

CONCLUSION

Completion and analysis of the database will require standardization to the extent possible, which implies derivation of estimates through common methods for some key variables (wind speed, dead fuel moisture content); parts of the database have already been used to validate the results of laboratory-based modeling of fire spread rate (Rossa 2017; Rossa and Fernandes 2018). Then we will be able to characterize and synthesize fire behavior patterns and assess how they vary with top-down and bottom-up environmental drivers, expanding the current options for empirically-based estimation of fire behavior characteristics, developing calibrated fire behavior fuel models for global use in Rothermel's based software, and establishing links with fire danger rating systems.

The BONFIRE project will hopefully provide a sounder foundation for fire management and fire research applications, including a data repository available for further research, and will increase the understanding of fire regime shifts in relation to global change. To keep up with BONFIRE developments,

Table 1—Surface fuel complexes distribution (%) by climate type. Combinations accounting for <1.5% of the total number of observations are not displayed.

Koppen-Geiger climate classification	Grass	Grass + litter	Grass + shrub	Litter	Litter + shrub	Shrub
Equatorial savannah with dry winter	3.1					
Steppe climate - Hot steppe / desert	3.6	10.4	3.8			
Desert climate - Hot steppe / desert	1.9					
Warm temperate climate, fully humid - Hot summer	1.7	2.2	1.5	1.9		
Warm temperate climate, fully humid - Warm summer	6.1			2.6	1.6	3.9
Warm temperate climate with dry summer - Hot summer				2.6		2.5
Warm temperate climate with dry summer - Warm summer				3.2	1.7	2.7
Warm temperate climate with dry winter - Hot summer		5.8				
Snow climate, fully humid - Warm summer	2.5					

visit https://www.researchgate.net/project/BONFIRE-gloBal-scale-analysis-and-mOdelliNg-of-FIRE-behaviour-potential-PTDC-AAG-MAA-2656-2014.

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