Forest Ecology and Management 317 (2014) 26–40

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

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

Wildland fire emissions, carbon and climate: Characterizing wildland fuels

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ARTICLE INFO

Article history:
Available online 12 April 2013

Keywords:
Classification
Sampling
Remote sensing
Physical
Chemical
Scaling

ABSTRACT

Smoke from biomass fires makes up a substantial portion of global greenhouse gas, aerosol, and black carbon (GHG/A/BC) emissions. Understanding how fuel characteristics and conditions affect fire occurrence and extent, combustion dynamics, and fuel consumption is critical for making accurate, reliable estimates of emissions production at local, regional, national, and global scales. The type, amount, characteristics, and condition of wildland fuels affect combustion and emissions during wildland and prescribed fires. Description of fuel elements has focused on those needed for fire spread and fire danger prediction. Knowledge of physical and chemical properties for a limited number of plant species exists. Fuel beds with potential for high impact on smoldering emissions are not described well. An assortment of systems, methods, analytical techniques, and technologies have been used and are being developed to describe, classify, and map wildland fuels for a variety of applications. Older systems do not contain the necessary information to describe realistically the wildland fuel complex. While new tools provide needed detail, cost effectiveness to produce a reliable national fuels inventory has not been demonstrated. Climate change-related effects on vegetation growth and fuel distribution may affect the amount of GHG/A/BC emissions from wildland fires. A fundamental understanding of the relationships between fuel characteristics, fuel conditions, fire occurrence, combustion dynamics, and GHG/A/BC emissions is needed to aid strategy development to mitigate the expected effects of climate change.

Published by Elsevier B.V.

1. Introduction

Total land area of the United States (US) is estimated to be 9,161,966 km^2 (Central Intelligence Agency, 2009). Approximately 65% of the conterminous US (Fry et al., 2011), 74% of Alaska, 55% of Hawaii, and 62% of Puerto Rico is occupied by natural vegetation (Homer et al., 2004). The vegetation types of the US encompass most of the vegetation biomes found in North America, which includes tundra, boreal, temperate, and tropical (Barbour and Billings, 2000; Brown et al., 2000). Within a biome, all species have the potential to burn depending on plant and environmental conditions, although the plant organs burned, the amount and type of plants consumed, and the nature of the combustion process vary widely.

Fire is a global phenomenon that releases the energy stored by plants during photosynthesis. Live and dead vegetation is the fuel source for wildland fires. Consideration of the inter-relationship between vegetation and fuel is, therefore, critical for evaluating likely changes associated with a changing climate. Development of novel climatic conditions in a greenhouse world is likely to affect future fire regimes (McKenzie et al., 2004) and create "no-analog" vegetation communities (Williams and Jackson, 2007), which may affect the biological, physical, and chemical characteristics of fuel sources for wildland fires (Bowman et al., 2009). Open biomass burning is the largest contributor of fine particulate matter ($PM_{2.5}$) and the second largest contributor of black carbon to the atmosphere (US Environmental Protection Agency, 2012), so an understanding of the ecology of vegetation and fuels provides important context for discussions of wildfire and emissions of greenhouse gases, aerosols, and black carbon (GHG/A/BC). Estimates of past, current, and projected future emissions from wildland fires are critical for understanding the carbon cycle, including the effects of carbon emissions on atmospheric processes; measuring and assessing effects on air quality; and producing accurate projections of climate change. The objective of this paper is to synthesize the state of science regarding wildland fuels as they relate to GHG/A/BC emissions. The synthesis will examine the assortment of systems, methods, analytical techniques, and technologies that have been used and are being developed to describe, classify, and map wildland fuels and their characteristics.

For a given wildland fire, the fire size, the amount and type of fuel combusted, and the combustion efficiency determine emissions production and composition. Seiler and Crutzen (1980)

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0378-1127/$ - see front matter Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.foreco.2013.02.037

proposed that the mass of wildland fuels burned annually could be estimated as a function of total area burned, the mass per unit area available for combustion (available fuel) within the burned area, and the fraction of wildland fuel actually consumed during the combustion process. The product of the consumed wildland fuel mass and appropriate emission factors yields an estimate of emissions by pollutant species, including greenhouse gases, aerosols, and black carbon, that can be summed to determine total emissions (French et al., 2011). Emission factors differ with fuel type and combustion phase (i.e., flaming, smoldering, and glowing), so attributing the proportion of total consumption to the different combustion phases is important for accurate estimation of total emissions (Hardy et al., 2001; Ward and Hardy, 1991; Ward and Radke, 1993).

Loading (mass/unit area), fuel consumption (mass/unit area), and emission factor (mass of chemical species produced/mass of fuel burned) are the primary variables tied directly to vegetation characteristics in the process used to estimate emissions production. Substantial error and uncertainty can be introduced to emissions estimates by our current inability to accurately quantify the amount of fuel present and consumed within burned areas and the type and efficiency of combustion of the fuels (flaming, smoldering, or glowing) (French et al., 2011; Mobley et al., 1976; Ottmar et al., 2008; Peterson, 1987). Chemical composition of a wildland fuel and the type and efficiency of combustion determine the composition of the gaseous and particulate emissions produced. It is, therefore, critical to carefully quantify all of the different variables necessary in these calculations to minimize compounding error and generate an accurate estimate of emissions with quantifiable levels of error and uncertainty (French et al., 2004). A full and accurate retrospective accounting is challenging for large areas, long time scales, and complex fuelbeds, when the necessary data are scarce or lacking. Similarly, prospective accounting is challenging in light of uncertainty about future fire pattern, intensity, and frequency coupled with changes in vegetation associated with climate change and elevated carbon dioxide levels (Miller and Urban, 1999; Whitlock et al., 2003).

Shifts in vegetation growth and distribution associated with climate change may alter fuel composition, amount, arrangement, and condition. Climate change-induced increases in area burned (Littell et al., 2009; McKenzie et al., 2004), shifts in vegetation type (Whitlock et al., 2003), and changes in fire severity (Marlon et al., 2006) will likely affect GHG/A/BC emissions from biomass burning. Climate change may also change fire occurrence timing, location, and size; the intensity and severity of prospective fires; the type and amount of fuel consumed; and the characteristics of combustion (Bowman et al., 2009; Hessl, 2011; Sandberg and Dost, 1990). Disturbances other than fire, such as insect outbreaks and severe wind events, also affect fuelbed properties, which can alter the intensity, severity, location, and timing of fire occurrence (Whitlock et al., 2003; Williams and Jackson, 2007), and therefore, the quantity and composition of emissions produced for a given geographic area and time period. The direction, timing, and magnitude of changes in GHG/A/BC emissions will likely vary for a given location or spatial domain and time period (Hessl, 2011).

2. Classification of wildland fuels

Vegetation is grouped into classes or communities based on similarities in species occurrence and abundance. Attributes of the vegetation assemblage may be used to describe fuelbed characteristics for different vegetation classes. It should be noted, however, that, in addition to among-vegetation-class differences in fuelbed characteristics, within-vegetation-class variability is common and often substantial (Hall et al., 2006). Generalized relationships between vegetation communities and fuelbed characteristics that do not account for this variability, and any assessments or inferences made from such generalizations, may be fraught with uncertainty.

2.1. Vegetation

A vegetation classification is developed by grouping similar stands or plots into vegetation, or plant community, types (Tart et al., 2005). Various agencies and groups have used several vegetation classification systems yielding inconsistent systems for describing vegetation nationally in the United States. Examples of vegetation classifications that are based on the current composition of the flora include cover types as defined by the Society of American Foresters (Eyre, 1980) and the Society for Range Management (Shiflet, 1994). Alternatively, potential natural vegetation classification systems attempt to describe a site's biophysical capacity to support different species and species combinations, and are identified based on the composition of the species assemblage that is likely to dominate at the climax of succession in the absence of disturbance (Daubenmire, 1968; Franklin and Dyrness, 1988).

The National Vegetation Classification System (NVCS) was established to address the inconsistent application of different classification systems among agencies and groups (Federal Geographic Data Committee, 1997). Typically for classification systems, each class or type name represents a taxonomic group with defined limits, about which meaningful and reliable statements can be made (Jennings et al., 2009). The structure of the NVCS is based on five diagnostic criteria used to classify vegetation at all levels of the hierarchy: diagnostic species, dominant species, diagnostic growth forms, dominant growth forms, and compositional similarity (Fig. 1). The NVCS formalizes standards for data collection, data analysis, data presentation, and quality control

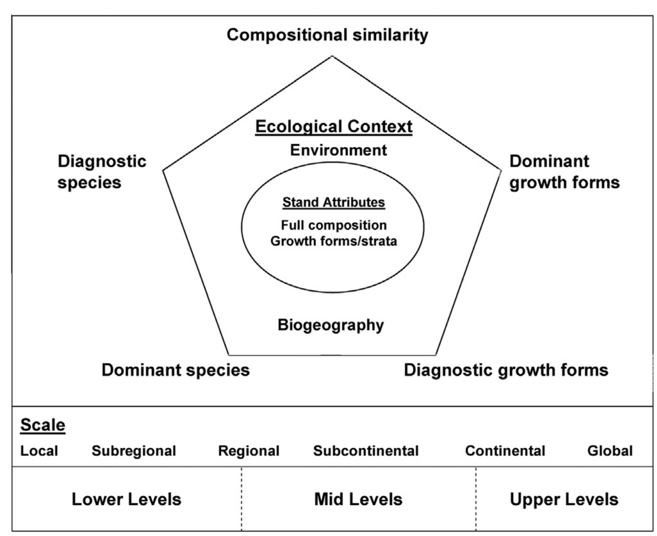

Fig. 1. The pentagon portrays the five vegetation criteria used to classify vegetation at all levels of the NVCS hierarchy. These criteria are arranged from the most fine-scaled on the left to the most broad-scaled on the right. The five criteria are derived from stand attributes or plot data (inside oval) and reflect the ecological context (outside oval) of the stand or plot. The ecological context includes environmental factors and biogeography considered at multiple scales, as well as natural and human disturbance regimes. The upper levels of the NVCS hierarchy are based on dominant and diagnostic growth forms that reflect environment at global to continental scales. The mid levels are based on dominant and diagnostic growth forms and compositional similarity reflecting biogeography and continental to regional environmental factors. The lower levels are based on diagnostic and/or dominant species and compositional similarity reflecting local to regional environmental factors (Fig. 2.1 from (Federal Geographic Data Committee, 2008)).