Chapter 6
Fuel and Fire Behavior Description

Learning Outcomes
Upon completion of this chapter, we expect you to be able to

1. Apply the descriptors of fuels to an area of vegetation with which you are familiar,
2. Distinguish amongst fuel particles, fuelbeds, fuel components, and fuel layers,
3. Diagram a fire burning in a grassland and apply the fire behavior descriptors to the flaming and smoldering combustion, and
4. Explain why the rate of spread and fireline intensity or flame size are crucial metrics in fire management

6.1 Introduction

Vegetation mediates both the effects of fire on ecosystems and human impacts on the fire regime. Independent of its biological nature, characterizing vegetation's ability to burn (i.e., as fuels) is useful for describing and modeling fire behavior and fire effects for multiple fire management applications. Fuel properties are highly variable in space and time. Analysis of fuels is a matter of scale, from the combustion at the scale of individual flames to the fire behavior scale to the landscape scale (Pyne et al. 1996).

This chapter addresses extrinsic fuel properties, those that exert quantifiable influence on fire behavior characteristics. In contrast, fuels' intrinsic properties are fundamental to fire ignition and spread (Pyne et al. 1996) but are unlikely to result in substantial variation in fire behavior at the scale measurable in the field (Cheney 1981). Intrinsic properties of fuels include chemical composition (including mineral

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content and readily volatilized constituents), heat content, particle density, thermal conductivity, and diffusivity (Chaps. 1–4). Fuel moisture is highly dynamic (See Chap. 11).

Wildland fires are classified according to the dominant fuel type being burned (e.g., a shrub fire is one burning in a shrubland) and the layer of fuel supporting fire spread (ground, surface, or crown fire). Ground fires burn organic matter in the soil, spreading very slowly. Surface fires can spread either slowly or rapidly as they burn leaf litter, fallen wood, and plants near the soil surface. Crown fires burn the foliage of trees and shrubs with high intensity. Fire behavior is described for various parts of a fire. This chapter introduces the fire behavior descriptors that are commonly measured or estimated by wildland fuel and fire managers and by fire scientists.

Fuels and fire behavior descriptors are generally shown as measures of central tendency, as means or medians of different measurements, but it should be recognized that both fuels and fires are generally quite variable in space and time. Measures of variability, as ranges or standard deviations, should be considered in sampling and analysis, for variability in fuels influences variability in fire behavior and effects. Measurements of central tendency and associated variability derive from sampling and statistical analyses. Many options are possible to optimize sampling to ensure unbiased and precise estimates while minimizing costs. Further discussion about sampling measurements of fuels and fire properties is beyond the scope of this book. In this chapter, we simply present the most commonly used extrinsic fuel properties and fire descriptors. Keane (2015) addressed many fuel-related topics, including fuel properties and inventory.

6.2 The Wildland Fuel Hierarchy

Wildland fuel description can be approached as a top-down hierarchy in terms of spatial resolution. Distinct levels of structural organization correspond to different scales of observation and heterogeneity in varying degrees. Here we will loosely follow Keane (2015), from coarse to fine scales (Fig. 6.1):

1. **Fuelbed is** a generic description of the complex of fuels occupying a given area.
2. **Fuel layer** or stratum results from the vertical stratification of the fuelbed into ground, surface, and canopy fuels (Fig. 6.2) that correspond with different combustion environments, respectively ground (or subterranean, or smoldering), surface, and crown fire. Although the boundary can be subjective, ground fuels typically comprise organic matter that does not contribute to flaming combustion. Ground fuels are in an advanced state of decomposition and overlaying the mineral soil; included are the duff (or humus) layer, peat, roots, and rotten woody fuels. Surface fuels refer to litter plus vegetation (grasses, forbs, and shrubs, including mosses and lichens in boreal ecosystems) within 2 m above ground (Keane 2015), especially for the purpose of using Rothermel's fire spread model (Chap. 7). Litter consists of fallen leaves, woody elements of various sizes,

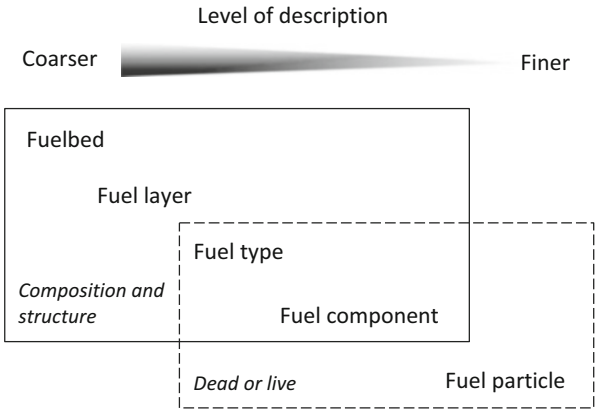

Fig. 6.1 Levels of wildland fuel description based on Keane (2015), from coarser (fuelbed) to finer (fuel particle), and how their properties are defined in broad terms

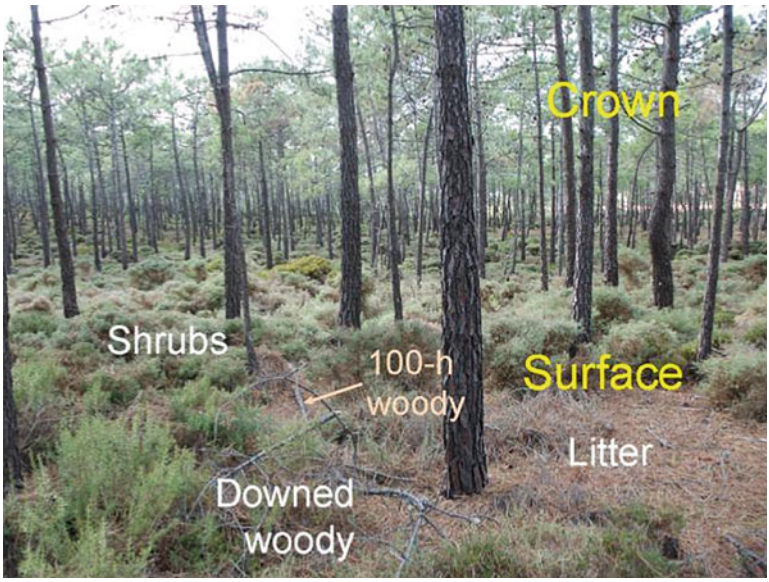

Fig. 6.2 Fuels in a maritime pine (*Pinus pinaster*) forest on the southwestern coast of Portugal consists of three fuel layers: ground (not visible), surface, and crown fuels. Surface fuels include three fuel types (litter, downed woody, and shrubs). One example fuel component is 100-h woody fuels (i.e., 25–75 mm in diameter). As litter and shrubs are codominant, surface fire behavior will develop in a litter-shrub fuel complex. (Photograph by P. Fernandes)

and bark and typically comprises a decomposing (fermentation) layer (F) and the fresh (undecomposed) layer (L) that drives fire spread. Slash (or activity) fuels will add to the previous categories after silvicultural operations, including canopy fuel treatments. The canopy (or aerial) layer encompasses all biomass above 2 m, regardless of its nature, and is often divided into ladder and crown fuels. Note that the same term can differ in meaning among countries or systems. In Australia,

surface fuels designate litter only and the following layers are also considered: near-surface fuels composed of grasses and low shrubs and suspended material from the overstory, elevated fuels (tall shrubs), and bark fuels on the bole and branches (Gould et al. 2007).

3. **Fuel type** describes the generic nature of fuels or the dominant fuels in the fuelbed, e.g., "grass". Again, the understanding of "fuel type" varies. In the Canadian Forest Fire Behavior Prediction (FBP) System, fuel type refers to a vegetation type with distinctive fire behavior characteristics.
4. **Fuel component** subdivides the fuel type as a function of size (e.g., "fine woody fuels") or physiological condition (e.g., "live shrub foliage"). The distribution of fuels by size class (usually <6, 6–25, 25–75, and >75 mm diameter) and whether they are dead or live profoundly influences fire behavior and both direct and indirect effects of fires (through fuel moisture content dynamics, Chap. 11).
5. **Fuel particle** refers to the individual fuel elements or units (e.g., twig, leaf, needle) that form the fuel complex at coarser scales and often define the calculation of aggregate fuel properties at those scales (Fig. 6.1).

6.3 Fuel Description

Various extrinsic fuel metrics are used to describe fuels (Table 6.1). These include the size and shape of particles and the amount and structure (including metrics of compactness and continuity) of fuelbeds, fuel layers, and fuel components.

The size and shape of individual particles influence ignitability, heat release rate, and burn duration. The size and shape of fuels are integrated into fire-spread models through surface area-to-volume (or mass) ratio. Size classes as a function of particle diameter or thickness are used to define nominal rates of dead fuel moisture content response (time-lag) to variation in atmospheric conditions (see Chap. 11). Size classes are used in summarizing the fuel loads and moisture contents that are the basis for fire behavior modeling and fuel inventories.

Fuel load, defined as the mass per unit area, plays a central role in fire science and management. Along with fuel moisture content (Chap. 11), fuel load determines fuel consumption and the amount of heat released during combustion. The amount of fuel consumed influences fire effects in vegetation and soils (See Chap. 9) and the effectiveness of fire control operations. Fuel load is needed to calculate fuel structure descriptors such as bulk density (Table 6.1), and fire intensity is an input to fire behavior and effects models. Fuels treatments are often designed to reduce fire hazard (See Chaps. 10 and 11). The degree to which fuel load contributes to fire behavior, especially to the flaming front properties, is termed fuel availability and depends on fuel structure and moisture. Fuel depth, bulk density, and packing ratio are descriptors of fuel structure that affect heat transfer and fire-spread rate. These descriptors are included in fire-spread rate models. Finally, the vertical discontinuity between the surface and canopy fuel layers is used to assess the likelihood of crown fire.

Table 6.1 Extrinsic fuel variables definitions, compiled from various sources

Scale	Variable	Symbol	Definition	Units
Fuel particle	Diameter	d	Diameter of a cylinder (generalized assumption)	m
	Surface area-to-volume ratio	σ	Particle surface area divided by its volume	m^{-1}
	Surface density	m/A	Mass of the particle (m) divided by its projected area (A)	kg m^{-2}, g cm^{-2}
	[a]Surface area-to-mass ratio	S_m	Particle surface area divided by its dry weight	m^2 kg^{-1}
Fuel complex	Load	w	Dry weight per unit area	kg m^{-2}, t ha^{-1}
	Depth, height	δ	Fuel layer or fuel complex thickness	m
	Bulk density	ρ_b	Dry weight per unit volume	kg m^{-3}
	[b,c]Packing ratio	β	ρ_b divided by particle density, the fuel bed volume fraction occupied by fuel	Dimensionless
	Canopy base height	CBH	Vertical distance between ground surface and the live canopy base	m
	[d]Fuel strata gap	FSG	Distance from the top of the surface fuel to the lower limit of the canopy constituted by ladder and live fuels	m

[a]Rossa and Fernandes (2018)
[b]Countryman and Philpot (1970) refer to 1/β as porosity
[c]Rothermel and Anderson (1966) define porosity as the void volume per unit of fuel surface area (m)
[d]Cruz et al. (2004)

The methods and variables used to describe wildland fuels are intrinsically dependent on the input requisites of the adopted fire behavior models. Empirical models for fire-spread rate, developed for specific or generic fuel types, seldom include the effect of more than one descriptor of fuel structure (Cruz et al. 2015). They can also altogether disregard fuel variation within a vegetation type, such as in the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992).

Rothermel's (1972) model of surface fire spread relies on sets of numerical fuel characteristics called fuel models that represent the fuels complex for fire behavior predictions. A set of 13 stylized fuel models organized in 4 groups (grass, shrub, litter, slash) depending on the vector of fire spread has been developed (Anderson 1982). Fuel models are widely used to predict fire behavior characteristics with applications that employ Rothermel's model. Each fuel model is described in terms of fuel load by size class, surface area-to-volume ratio, fuel depth, heat content, and moisture of extinction. As the 13 fuel models are insufficient to account for the variability in fuel characteristics found across vegetation types and ecosystems, including when multiple fuel layers are considered, additional fuel models have been developed, including a set of forty for the USA (Scott and Burgan 2005). Of

most importance for management applications, the parameters of custom fuel models should be calibrated and optimized such that predicted fire behavior matches observed fire behavior (Hough and Albini 1978; Cruz and Fernandes 2008; Ascoli et al. 2015).

Various methods have been developed to assess and quantify fuels, directly and indirectly, and destructively or not. Catchpole and Wheeler (1992) reviewed the existing types of techniques and distinguished between:

1. **Direct sampling**, based on destructive (and costly) fuel sampling and is usually restricted to research studies that require accurate estimates of fuel load. Fuels are harvested from within quadrats of variable size, are bagged, and then processed in the laboratory, which includes sorting, weighing, and oven drying by size class and dead or live condition. Direct sampling also includes scoring or rating (from nil to extreme) fuel hazard by fuel layer (Gould et al. 2007), and measurements of fuel structure, such as the depth (or height) of the existing fuel layers, and the ground covered by individual fuel layers. In the latter case, linear or planar intercept (or transect) methods are used (Van Wagner 1968; Brown 1971), but also point contact techniques.
2. **Calibrated visual estimation**, where comparison with reference information is used to estimate fuel loads (Keane and Dickinson 2007) or assign fuel models (Anderson 1982). Photo keys or photo series are a common tool for this purpose (Fig. 6.3). Photo series typically associate each photo to a fuel model and quantify fuel loads for the depicted situation, plus fire behavior characteristics and fire control difficulty for a given weather scenario.
3. **Double sampling**, where a fuel parameter is estimated using a two-stage approach. In the first stage, a sample is taken to develop either a ratio or regression that relates a variable of interest to another more easily measured variable. In the second phase, the more easily measured variable is collected, and the variable of interest is estimated using the ratio or regression developed in the first phase. For example, a regression that relates fuel load and a metric of fuel structure such as cover or depth or even time since disturbance (see Chap. 11) can be developed by collecting data on the two variables. The secondary, often larger sample, of the more easily measured variable can be collected and the variable of interest can be estimated by applying the developed regression to the measured variable.

6.4 Fire Description

Wildland fires are often simply classified qualitatively according to the dominant fuel type being burned or by the layer of fuel supporting fire spread. However, quantitative metrics describing fires are available and very useful in fire management.

Ericaceous Shrub 17

Site Information

Location	Clear Creek State Forest, Jefferson County, Pennsylvania
Overstory metrics	103 trees/acre; basal area 95 feet/acre; stocking 69 percent
Overstory composition	Chestnut oak, red maple, northern red oak, white oak
Understory composition	Mountain laurel
Aspect/elevation/slope	South; 1,800 feet; 5 percent
Stand history	Gypsy moth mortality and salvage harvest in late 1980s

Fuel Characteristics

Leaf litter	3.4 tons/acre	Litter cover	100 percent
1-hour woody	4.1 tons/acre	Shrub cover	95 percent
10-hour woody	4.5 tons/acre	Ave. fuel height	3.3 feet
100-hour woody	6.6 tons/acre	Ave. fuel moisture	15 percent
1,000-hour woody	8.2 tons/acre	Optimal fuel model	5*
Total fuels	26.8 tons/acre	Min/max fuel model	10*, 4*

Weather and Fire Behavior Data

Air temperature	64 °F	Burn date/time	01 May 2003, 1200
Relative humidity	33 percent	Firing device	Drip torch
Wind direction	South	Firing pattern	Strip-head fire
Wind speed	1 to 3 miles/hour	Flame lengths	5 to 10 feet
Cloud cover	50 percent	Rates of spread	5 to 10 feet/minute
Days since rain, amt.	3, 0.25 inch		

Fig. 6.3 An extract of the photo guide for estimating fuel loads and fire behavior in mixed-oak forests of the Mid-Atlantic Region in the USA (Brose 2009). This photo guide includes photographs taken before and during burning, the fuel model(s) assigned, site and detailed fuel data, and observed fire behavior and the corresponding weather conditions

From a top view (Fig. 6.4), one fire includes at any point in time different locations with different behavior. Therefore the description of fire behavior is commonly provided for a specific part of a fire. The ignition location is referred to as the origin of the fire. In the absence of wind and slope and in perfectly homogeneous fuels, fires spread with a circular shape following ignition. However, in the presence of wind or slope, fires spread in an elliptical shape. The portion of the fire that is spreading upslope and with the wind is called the headfire and is associated with the most active fire behavior. The section of the fire spreading against the wind and/or slope is called the backfire, and typically has the shortest flames and is the slowest moving portion of the fire. The section of the fire perimeter associated with the backfire is commonly referred to as the back, heel, or rear of the fire. The fire spreading on the sides is moving perpendicular to the wind and is referred to as flank fire. Fire behavior along the flanks is somewhere between the headfire and backfire. The shape of the fire perimeter is tightly linked to variability and interactions among the fire environment, topography, and fuels. This variability can result in a number of unique features along the fire perimeter. Fingers are formed when part of the fire front spreads faster than the surrounding front, resulting in the formation of a long narrow strip of fire. Spot fires are formed when firebrands are transported beyond the fire front and ignite new fires. These present especially hazardous conditions for fire managers. Spotting is discussed further in Chap. 8. In other cases, variability in fire

Fig. 6.4 Fires grow from the point of ignition, spreading faster with the wind and up the slope. The head, flank, and back of fires differ in their fire behavior characteristics. All fires have islands that are unburned or burned with such low severity that they are refugia for plants and animals from the effects of fires. Fire suppression efforts often progress from the back to the head of the fire, as the latter can be too intense for effective and safe attack. (Drawn by Heather Heward, University of Idaho)

behavior and spread can result in patches of unburned fuels within the fire perimeter. These are often referred to as islands or fire refugia; see Chap. 12 for more discussion on fire refugia as they can influence the survival of animals and rates of vegetation recovery post fire.

For fire management purposes, flame front characteristics, and in particular, how fast fires spread, have been the primary focus of fire behavior measurement and modeling. Additional metrics describe the amount, rate, and duration of heat release, as well as flame geometry (Table 6.2). We draw upon Cheney (1981) and Alexander (1982) for the following fire descriptors.

From a side view (Fig. 6.5), the flaming fire front has three dimensions: depth (D), height (H), and length (L). Flame depth (D) increases linearly with the rate of spread (R), and D/R defines the residence time of the flame (t_R). Flame size, either H or L, is a visible and obvious manifestation of energy release. Thus, flame size is a common fire descriptor, despite subjectivity in definition and measurement.

From the perspective of energy, Byram (1959) coined the concept of fireline intensity (I_B) to quantify the heat release rate in the active combustion zone per unit length of the fire front (See Figs. 6.4 and 6.5). Fireline intensity is calculated as:

Table 6.2 Fire behavior metrics definitions. Compiled from Byram (1959), Cheney (1981, 1990), Alexander (1982), and Andrews (2018), unless otherwise stated

Variable	Symbol	Definition	Units
[a]Rate of spread	R	Linear advance of the flaming fire front per unit of time	[b]m s^{-1}, m min^{-1}, m h^{-1}, km h^{-1}
Residence time	t_R	Flaming combustion duration, or the length of time for the flame front to pass a given point	s, min
Burn-out time, reaction time	t_B	Total combustion duration, or the time for all fuel fractions to burn out	s, min
Flame height	H	Mean extension of the flame front measured vertically from the ground	m
Flame angle	A_f	Angle between the fire front and the unburned fuel bed	°
Flame tilt angle	A_T	Angle between the vertical and the fire front	°
Flame depth	D	Width of the flaming front (the active combustion zone, i.e. with continuous flame)	m
[c]Flame length	L	Mean distance from the flame extremity to the mid-point of the flaming front	m
Reaction intensity, combustion rate, area-fire intensity	I_R	Heat release per unit area per unit of time within the flaming front	kW m^{-2}
Heat release	H_A	Heat release per unit area within the flaming front	kJ m^{-2}
[d]Fireline intensity	I_B	Heat release within the flaming front per unit time and unit length of the fire front	kW m^{-1}
[e]Power of the fire	PWR	Heat release per unit time within the flaming zone, integrated around the fire perimeter	MW

[a]Equivalent metrics can be calculated for the perimeter (e.g., m h^{-1}) and area (ha h^{-1}) of the fire as a whole (Byram 1959)
[b]Usually dependent on the scale of application
[c]Calculated from H and A_f or A_T; some authors consider the leading flame edge rather than its central axis (Nelson and Adkins 1986; Catchpole et al. 1993)
[d]Fire intensity (Byram 1959), Byram's fireline intensity, or frontal fire intensity
[e]Harris et al. (2012)

$$I_B = h_c\, w\, R \tag{6.1}$$

in units of kW m^{-1} and where h_c is the low heat of combustion (kJ kg^{-1}), w is the amount of fuel available for flaming combustion (kg m^{-2}), and R is the rate of fire spread (m s^{-1}). To estimate h_c, the low heat content ΔHL is generally used but should ideally be adjusted for losses due to water evaporation, radiation, and incomplete combustion to give heat yield ΔHY (see Chap. 3). However, given the

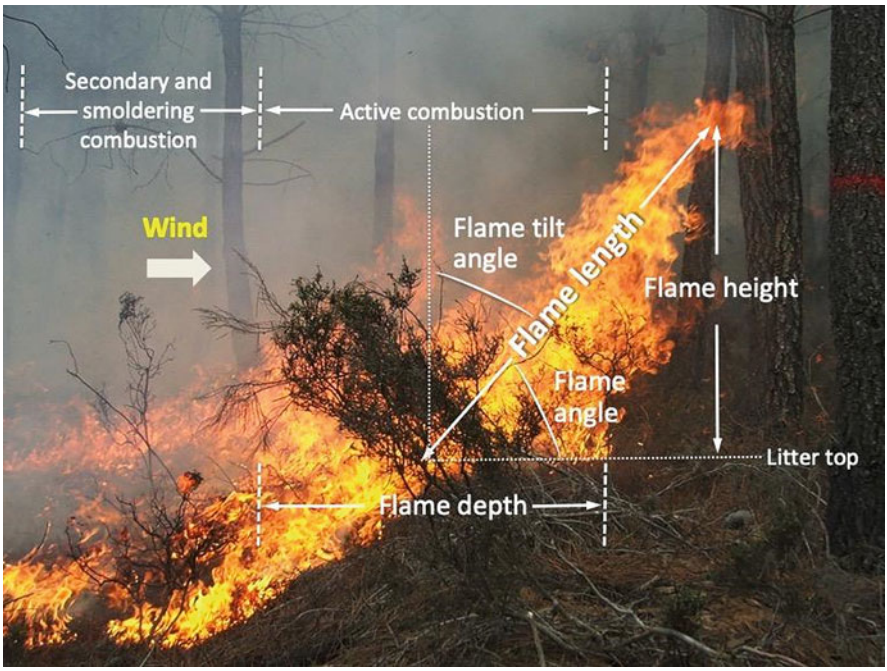

Fig. 6.5 Side view of an experimental surface headfire in a maritime pine stand (*Pinus pinaster*) in Portugal. Flame geometry descriptors and the energy release stages during and after the passage of the flame front are shown. (Adapted from Cheney 1981 and Alexander 1982 with background photograph by P. Fernandes). Note that smoldering is an important component of fire behavior with consequences for ecological effects

inherent difficulty in making these adjustments, and because heat content varies little among different fuels, h_c is often assumed constant at about 18,000–18,700 kJ kg^{-1} (e.g., Albini 1976; Forestry Canada Fire Danger Group 1992). The greatest uncertainty in calculating I_B lies in estimating w, especially in fuel complexes that are highly heterogeneous in compactness, moisture, and particle size. In the end, the impact of these shortcomings is relatively minor because variation in I_B is primarily a function of R.

Multiple empirical relationships have been derived over the years that relate fireline intensity I_B and flame length L for different fuel types (Alexander and Cruz 2012). Byram (1959) relationship is the most commonly used and indicates that L (m) scales approximately at the square root of I_B (kW m^{-1}):

$$L = 0.0775\, I_B{}^{0.46} \tag{6.2}$$

For crown fires the relationship of Thomas (1963) based on convection theory is more commonly preferred, e.g., Rothermel (1991):

$$L = 0.02665\, I_B^{0.667} \tag{6.3}$$

The reciprocals of these equations can be used to estimate I_B from L, with equation coefficients respectively 259.833 and 2.174 for Eq. (6.2), and 229 and 1.5 for Eq. (6.3).

I_B is a simple quantity that cannot be observed or measured but is a single figure synthesis of the most relevant properties of a wildland fire front. Fire managers commonly use fireline intensity to assess fire control difficulty (Hirsch and Martell 1996) and aboveground fire effects such as crown scorch height on trees (Van Wagner 1973; Michaletz and Johnson 2006). However, as discussed at length by Cheney (1990), I_B is of limited value for comparing fires in different fuel structures because the same value can correspond to quite different fire behaviors. For example, a fast-moving fire in grassland can have the same I_B as a slow-moving fire in slash fuels because the latter consumes much more fuel.

Remote sensing technology is allowing substantial advances in the realms of pyrogeography. Fire radiative power (FRP) is the rate of energy emission per unit area (in kW or MW) from fires as derived from thermal remote sensing in the middle infrared region. FRP correlates with reaction intensity and I_B and can be calculated in kW m^{-1} for a fire front by summing individual pixel FRP values and dividing the result by the length of the fire front (Wooster et al. 2003). Thus, FRP can be expressed as the radiant component of I_B.

Many of these fire descriptor variables that describe the energy output of a wildland fire front are interrelated. For example, heat release per unit area (H_A, kJ m^{-2}) is calculated as the product of heat of combustion (h_c, kJ kg^{-1}) by fuel load (w, kg m^{-2}). Reaction intensity (I_R, kW m^{-2}), the heat per unit area released per unit time, is calculated by dividing heat per unit area (H_A, kJ m^{-2}) by the residence time (t_R, s). Also, the rate of spread (R, m s^{-1}) can be calculated by dividing flame depth (D, m) by residence time (t_R, s). These relations combined with Eq. (6.1) are shown in the following equalities:

$$I_R = \frac{H_A}{t_R} = \frac{h_c w}{t_R} = \frac{I_B}{D} = \frac{I_B}{t_R R} \tag{6.4}$$

From Eq. (6.4) we see that I_B can be estimated as:

$$I_B = I_R t_R R \tag{6.5}$$

This is the approach followed by Albini (1976) and used in the fire behavior modeling and effects tools based on Rothermel's model. Using Eq. (6.5) avoids estimating the amount of fuel consumed in the active flaming front but requires a good estimation of t_R, which currently cannot be provided because fuel complex characteristics are ignored in its calculation (Catchpole et al. 1998). Consequently, Eq. (6.5) typically produces I_B values that are 2–3 times lower than those calculated

according to Byram's (1959) formulation (Cruz and Alexander 2010). As a result, predictions of crown fire transition based on I_B from Eq. (6.5) are not consistent with the transition model (Van Wagner 1977, see Chap. 7). The reader should be aware of these differences and implications.

6.5 Implications

Fuel chemistry, combustion characteristics, and energy production and transfer were discussed in Chaps. 1–5 without specific considerations of the extrinsic physical properties of fuel particles and complexes that influence fire behavior. In this chapter, we focus on fuel descriptors, beyond their intrinsic thermochemical properties, and on the most commonly used fire behavior descriptors. These descriptors are attempts to simplify and model entities that vary in space and time, and the recognition of this variability is important. However, for understanding the relationships between fuels and fire and for practical implications in fire management, simple descriptors are fundamental to support strategies and decisions.

The limits for wildfire suppression or for the use of prescribed fire are generally established as a function of flame length or fireline intensity. The difficulties of controlling a fire and the threat to the safety of fire fighters and people, in general, are associated with fast-spreading fires. Furthermore, models for the rate of spread require knowledge of the main characteristics of the fuel particles and the fuel complexes involved. These issues associated with fire propagation are discussed in Chap. 7.

For the understanding of the processes of crown fires, the concept of canopy bulk density is fundamental, as are the concepts of crown base height or fuel strata and gaps between them. For spotting, the properties of fuel particles, such as surface density, are relevant to understanding their possible role as firebrands. These aspects are discussed in Chap. 8.

Fire behavior is directly associated with fire effects. For example, whether trees and large shrubs survive fires often depends on the intensity of flaming combustion. The degree of canopy scorch and stem char heights are correlated with H, L, and I_B. Other ecological effects are more closely related to duff consumption and soil heating. These depend on the downward heat flux and are controlled by the moisture, compactness, and composition (e.g., coarse woody fuels with long burn-out times) of the organic matter on and in the soil (Hartford and Frandsen 1992). The use of total fuel consumption w_T instead of w in the calculation of I_B, H_A, and I_R (in this case using burn-out time t_B), embraces all of the energy release phases (See Chap. 2), and is therefore expected to increase the association between fire behavior metrics and some fire effects (See Chap. 9).

The recognition that fires and fire regimes may change with time and that fuels are dynamic entities that are influenced by management are discussed in Chaps. 10 and 11 using the descriptors presented in this chapter. Many other relations between fuel and fire properties are present in the integrated fire management examples of Chap. 13.

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