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PERSPECTIVE

Fire in focus: Clarifying metrics and terminology for better ecological insight

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Abstract

1. Changing fire regimes are profoundly impacting ecosystems and society, requiring rapid advancement in fire-related knowledge within and across disciplines. Given the influx of new disciplines into the fire field, a lack of transparent vocabulary for the application and interpretation of fire regime attributes and fire metrics impedes the capacity to scale ecological knowledge across ecosystems and continents.
2. In this article, we acknowledge there are many ways to define or measure fire metrics, but demonstrate how precision and context are important for interpreting fire effects on biota. We illustrate the concept of linking fire metrics to specific relevant ecological mechanisms, using plants as an example.
3. *Synthesis and applications*. This article demonstrates how considering the processes through which fire influences individuals, populations, communities, and ecosystems acknowledges the connectivity between energetic, temporal, and spatial attributes of fire. This framework can help researchers and practitioners, particularly those new to the field, select fire metrics for research and management, interpret previous studies, and form a growing body of knowledge on fire-related change.

KEYWORDS
fire ecology, fire frequency, fire intensity, fire interval, fire regimes, fire severity, fire size, pyrodiversity

Fire regimes are changing globally, influencing ecological processes with impacts on society and the environment (Duane et al., 2021). These escalating fire challenges require trans-disciplinary research with diverse researcher and practitioner input (Kelly et al., 2023).

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To effectively include the influx of diverse practitioners researching the ecological impacts of fire, a shared understanding of the definition of fire, fire regimes, fire regime attributes, and the fire metrics used to characterise and understand them is needed (Table 1). Key to disentangling the complex effects of fire and to foster a shared understanding across disciplines is the use of transparent and intentional language in the way attributes of the fire regime are referenced, measured, and described through metrics. The need for this focused conversation on metrics was identified through observed inconsistencies in the use of fire terminology, including among ecologists and fire scientists working in different parts of the world. Consistent and transparent terminology is important if research is to be interpretable and scalable across ecosystems and continents. Terminology and metrics used in ecology to describe fire regimes and individual fire events continue to expand, and accordingly, we as researchers and practitioners need to be as clear as possible in our words and concepts.

Fire events, incorporating spatial and energetic attributes, recur in time to form a fire regime (Archibald et al., 2013; Figure 1). The specific attributes used to define the fire regime have evolved over time (Table 1; Gill, 1975; Krebs et al., 2010), with contemporary definitions including fire intensity, type, severity (energetic attributes), frequency, seasonality (temporal attributes), size and spatial configuration (temporal attributes). Species have adapted to the effects of particular fire regimes through co-evolution over millennia (He et al., 2019; Keeley, Bond, et al., 2011). While the fire regime is a useful concept to group the complex spatiotemporal attributes of fire (Krebs et al., 2010)—it does not prescribe which attributes and associated metrics are important for different ecological processes of interest (Gill & Allan, 2008).

To understand how changing fire regimes may impact ecosystems more mechanistically, we, the research community, often need to examine expressions of fire regime attributes, measured or defined through different fire metrics. This is necessary for several reasons: fire regime attributes themselves can be very difficult to measure (e.g. fire intensity); and in many places, fire regimes operate over broad time scales (e.g. centuries to millennia), and thus, the outcome of changing fire regimes (e.g. increased fire frequency) must be inferred from fire metrics (e.g. occurrence of a short-interval reburn). Here, we group the attributes of fire into three categories: energetic, temporal and spatial (Figure 1), and describe key fire metrics that may be used in research to inform fire regime attributes and why. Using summary tables (Tables S1–S3), we demonstrate existing ambiguity surrounding the use and application of fire metrics, suggest working definitions, and provide example applications of fire metrics based on ecological processes of interest.

1 | ENERGETIC ATTRIBUTES

The energetic attributes of the fire regime include 'fire intensity', 'fire type' and 'fire severity', which describe energy release from fire (fire intensity; Figure 1a), the strata that the fire burns (i.e. ground, surface or crown; fire type), and the immediate impacts on vegetation and soils (fire severity; Keeley, 2009). Fire type is used descriptively to broadly qualify fire regimes into ground, surface, or crown fire regimes, based on fire intensity and severity metrics (Murphy et al., 2013; Pausas, 2015). We note that the term 'fire type' has also been used to differentiate between wildfire and prescribed fire (Grau-Andrés et al., 2024; Jolly et al., 2022). While this distinction is

TABLE 1 Key terms used in this manuscript.

Term	Definition
Fire	Our use of the term 'fire' includes all types of wildland fire, including wildfire (bushfire), prescribed fire and cultural fire. Combustion from wildland fire includes flaming combustion (burning that releases flames) and smouldering combustion (burning that releases no flames), as smoke is an important and impactful product of fire-related processes
Fire regime	Fire regimes are the spatial, temporal and energetic patterns of fires in a given spatial area over a given time period (Krebs et al., 2010) Traditionally fire regimes were defined by the attributes fire frequency, intensity, fire type and seasonality (Agee, 1996; Gill, 1975). Later, definitions expanded to incorporate other ecologically important characteristics of fire, including attributes such as fire size, spatial configuration (shape and complexity) and fire severity (impacts of intensity on biota) (Krebs et al., 2010). Today many studies use varying space–time windows to describe the fire regime, so being specific in any one study about what constitutes the fire regime is important (Krebs et al., 2010)
Fire regime attributes	The energetic, temporal, and spatial attributes of fires make up fire regimes. Energetic attributes include fire intensity, fire type, and fire severity. Temporal attributes include fire frequency and seasonality. Spatial attributes include fire size and spatial configuration (shape and patchiness) (Gill, 1975; Krebs et al., 2010)
Fire metrics	Here we define 'fire metrics' as the quantifiable characteristics of fire(s) used to study the ecological effects of different fire regime attributes. Fire metrics ultimately contribute to characterising fire regimes and their ecological impacts

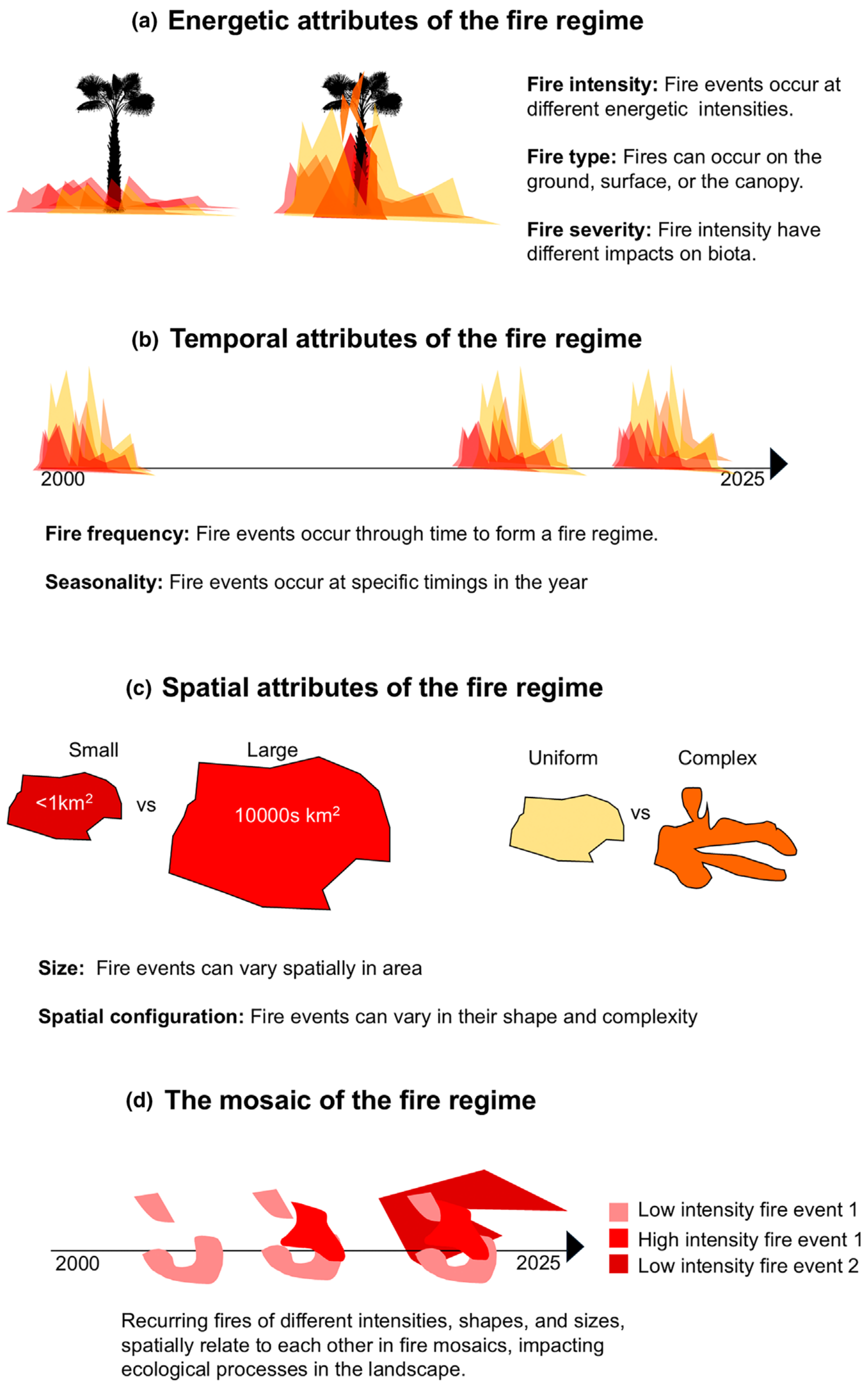

FIGURE 1 The energetic, temporal and spatial attributes of the fire regime. (a) The energetic attributes, including fire intensity, fire type and fire severity. (b) The temporal attributes, including fire frequency and seasonality. (c) The spatial attributes, including size and spatial configuration (shape and patchiness). (d) The 'mosaic' of the fire regime, which describes how recurrent fires of different types can spatiotemporally relate together in the landscape.

often informative, we advise against this usage when describing energetic attributes of fire regimes, owing to the inherent differences in seasonality between planned and unplanned fires, and because while there are often energetic differences between prescribed and wildfires, this is not always the case. In general, the metrics that quantify fire intensity and fire severity are a common source of ambiguity in fire research (Keeley, 2009; Table S1).

Fire intensity is extremely challenging to measure in practice; hence, there are a number of proxies that are used to quantify the energetic output of fire. These include metrics such as fireline intensity, flame length and height, soil temperature, fire temperature, fire radiative power and combustion duration (Table S1; Chatzopoulos-Vouzoglanis et al., 2024; Gagnon et al., 2015; Tada et al., 2024). Care must be taken when utilising these metrics. For example, fire temperature (e.g.°C) is often used as a proxy of fire intensity (kW/m) and can be used in various ways, from the hottest temperature reached to the average temperature across the duration of the fire event, and can be measured in the soil or above the surface (Auld & Bradstock, 1996; Keeley & McGinnis, 2007). However, soil temperature may not always be correlated with the energy released during a fire event (Keeley, 2009), since soil has excellent insulative properties, particularly at depths of >10 cm (Auld & Bradstock, 1996). Accordingly, soil temperature is only a relevant metric of fire intensity for temperature-related processes occurring below ground. Specificity when using direct measures of energy output (kW/m^2) is also important. For example, exposure duration (in time) and its dynamics (how the energy output varies across that duration) play an important role in determining the impact of radiant heat on biota (Tada et al., 2024; Table S1).

Fire severity is used to characterise and quantify the wide-ranging ecological impacts of the energy output of a fire on biota and is strongly dependent on the traits of vegetation. Keeley (2009) highlighted several uses of the term 'fire severity' to refer to the consumption of biomass, tree mortality, and wider ecosystem impacts (Keeley, 2009). Still, the wide-ranging use and application of the term can lead to misinterpretation of the ecological impacts when comparisons are made within or between systems (Miller et al., 2023). Continuing to move towards consistent, or transparent application of a 'fire severity' metric is important in disseminating and applying knowledge across ecosystems and continents. For example, in conifer forests of North America, field-derived metrics of fire severity are often quantified using the percentage of tree mortality immediately following fire, or by combining field measures including mortality into a Composite Burn Index (CBI) (Hanson & North, 2009; Miller et al., 2023; Reilly et al., 2017; Saberi et al., 2022). However, in the resprouting eucalypt forests of southeastern Australia and the tropical Savannas of northern Australia, fire severity is almost exclusively quantified as the degree of scorch and consumption of foliage (Collins et al., 2021; Russell-Smith et al., 2015). In many ecosystems where resprouting is prevalent, 'topkill' can also be used as a metric of fire severity, referring to the death of plant or tree stems above ground, but not the entire individual (Hoffmann et al., 2009; Hoffmann & Solbrig, 2003). Since fire severity represents the change, or impact, on the ecosystem, it can be measured in a wide variety of ways, including the amount of nitrogen volatised in Savanna ecosystems (Smith et al., 2005). Differences in these metrics can have meaningful differences in interpretation, depending on the ecological processes studied and the legacies of interest (Table S1).

Using tree mortality as a metric of fire severity may disguise important ecological responses to fire, as energetic effects may be decoupled from tree mortality. As referenced above, resprouter species can survive fire by producing new shoots from meristematic tissues in the trunk, branches or basal organs (Clarke et al., 2013; Pausas, 2015; Pausas & Keeley, 2017). Resprouting is common globally among angiosperm plants, such as in the fynbos of South Africa, the Chilean Matorral (Keeley, Pausas, et al., 2011), the Brazilian Cerrado (Hoffmann et al., 2009), and across many hardwoods of the United States (FEIS, 2025). The energetic intensity of fire is important in these ecosystems: even though intense fire may not necessarily kill individuals, it can defoliate and modify canopy and bole structure, and substantially modify available faunal resources, understory microclimate, and transition carbon from live to dead pools (Clark-Wolf et al., 2022; Collins et al., 2023; Saberi & Harvey, 2023). Tree mortality and top-kill also do not necessarily explain the influence of fire severity on in situ seed store, as plants or stems can be fire-killed with or without consumption of canopy-stored seed (Harvey et al., 2014; Hood et al., 2018; Figure 2a), or heating of the soil seedbank (Tangney et al., 2020). These are important ecological considerations for interpreting impacts of fire on ecosystems. Tree mortality and top-kill post-fire may also be linked to other interacting abiotic conditions that occur prior to or after the fire event, such as human disturbance, insects, pathogens, drought, or previous fire frequency (Berenguer et al., 2021; Hood et al., 2018; Reilly et al., 2023; Saberi & Harvey, 2023; Talucci & Krawchuk, 2019). Fundamentally, the importance of the distinction between fire severity metrics, and the application of them, depends on the ecological process studied, and precise descriptions of the metrics and the ecological contexts are needed to compare across studies and systems (Knox & Clarke, 2016; Table S1).

2 | TEMPORAL ATTRIBUTES

The temporal attributes of the fire regime refer to the inter- and intra-annual timing of fires. The fire regime attribute 'fire frequency' generally refers to the overall temporal patterns of fire (e.g. broadly how often it occurs), and 'fire seasonality' refers to the timing within the year that fire events occur (Krebs et al., 2010). There are a range of fire metrics related to fire frequency that define how fires are distributed through time, which can have profound impacts on ecosystems and their biota. These include the specific metric referred to as fire frequency (the number of fires in a designated time), but also metrics such as minimum fire return interval and most recent fire interval (e.g. the time between fires), or the time since the last fire (Table S2). As a fire metric, season- defined as the time of year a given fire occurs- can provide important information to examine the phenological implications of fire events (Ooi, 2019; Table S2). However, care must be taken when using a term like 'season', as it can be used to refer to the time of year of a specific fire event, the typical range (or duration) of time in which fires are common within an ecosystem, or even the year in which a fire occurred (Table S2).

The metrics fire frequency and various definitions of fire return interval all pertain to the intra-annual patterns of fire (Table S2). They describe the number and timing of successive fires. The use and significance of these terms are distinct (Table S2; Figure 2c). The metric fire frequency, referring to the number of fires in a specified timeframe, may be useful to measure processes that do not depend on the time between fires per se, but rather the quantity of fires that may trigger a phenomenon (Pellegrini et al., 2018; Table S2). For example, some species accumulate and store their seeds in persistent soil seedbanks for many decades, often beyond the lifespan of singular individuals above ground (Angert et al., 2009). Each fire represents a potential germination event, with some seeds germinating and others retained in the soil. The more fire events that occur, the more opportunity for seeds to germinate and deplete the persistent seedbank (Duivenvoorden et al., 2024; Plumanns-Pouton, Kasel, et al., 2024). However, fire frequency does not account for interval-sensitive processes as directly as fire return interval (e.g. inter-fire seedling recruitment and maturation; Figure 2c). While fire interval and fire frequency are often correlated, this is not always the case. For example, three fires within 90 years

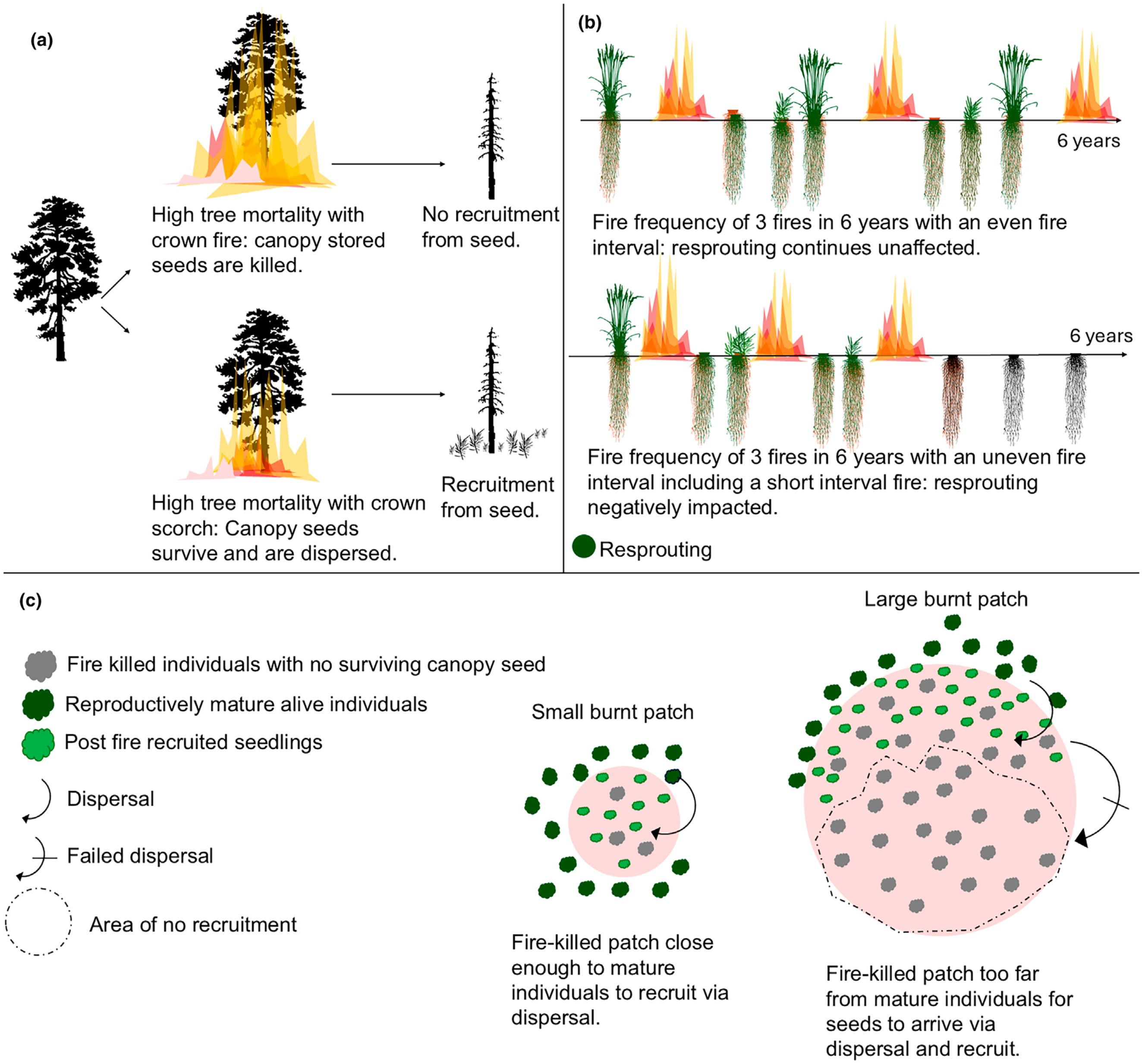

FIGURE 2 The ecological implications of fire metrics are distinct. (a) Quantifying fire severity as tree mortality may not be a sufficiently precise metric. In this example, the tree is fire sensitive and stores its seed in the canopy. While the trees in both examples are killed by the fire, one experiences total canopy consumption leaving no viable seeds, and the other experiences crown scorch, retaining some viable seed released into the environment. (b) The use of fire frequency or fire interval when selecting fire metrics to quantify the influence of temporal variation depends on what mechanisms are being studied in the ecosystem of interest. In this example, the two grassland areas experience the same frequency of fire for example three fires across the timeline, but the shorter fire interval in one area leads to local extinction of one species due to a disruption in the capacity to resprout and thus recover at short interval. (c) The spatial scale of any fire regime attribute that is area burnt at high severity plays an important role in determining the ecosystem effects. In this example, the mature individuals outside the small burnt patch can recolonise the entire patch through dispersal. In the larger patch, some recolonisation occurs on the edges, but some areas—that are too far from the nearest seed source—show no recruitment.

could have two intervals of 45 years, or equally, one interval of five and another of 85 years (Figure 2c). This is important because fire can only disrupt interval-sensitive processes, like recruitment, if the interval between *two* successive fires is shorter than the time taken to produce and accumulate seed (McColl-Gausden et al., 2022; Table S2).

Although time since fire is not specifically an attribute or metric of the fire regime, it is widely used to infer population and ecosystem changes that may occur under different inter-fire intervals. Time since fire can be effectively used in this regard to define lower and upper inter-fire intervals necessary for the persistence of plant populations where adults are highly fire sensitive and post-fire recruitment is dependent upon viable seed (Gosper et al., 2013; Plumanns-Pouton et al., 2023). Time since fire is also generally useful for examining a range of succession-related processes in different ecosystems, such as changing community assembly, light availability, biomass (fuel) accumulation and reproductive maturity (Table S2; Leduc et al., 2021; Plumanns-Pouton, Swan, et al., 2024). Indeed, in fire sensitive ecosystems where one fire event can lead to large and long-term (e.g. hundreds of years) shifts in species composition and forest structure, such as Amazonian forest (Barlow & Peres, 2008), the use of space-for-time studies to quantify post-fire succession may be the only viable means for predicting the outcome of changes to fire frequency and inter-fire interval.

Fire frequency related metrics are at risk of being used with ambiguity without additional energetic or spatial context. For example, many studies examining the effect of fire frequency and fire interval have not characterised the intensity, type or severity of fires. These differences in energetic attributes of fires have considerable consequences for the interpretation and comparability between studies (Table S2). A study examining plant population responses to short-interval, high-severity fire may come to very different conclusions than one examining short-interval, low-severity fires (Bennett et al., 2016). The difference—which has not been explicitly stated if *only* the term 'fire interval' is used—is that low and high-severity fires have vastly different impacts on plant survival and recruitment (Figure 1a; van Wagtendonk & Lutz, 2007). While we acknowledge the difficulty in balancing simplicity and nuance, we encourage researchers and practitioners to ensure clear and repeatable characterisation to allow meaningful comparisons between ecological studies across space and time.

3 | SPATIAL ATTRIBUTES

Spatial attributes of fire regimes describe the geographic footprint of fires and include fire size and spatial configuration. Spatial configuration can include the complexity of the fire perimeter, patchiness of burning within the fire perimeter, the size and arrangement of severities within fires, and also the mosaic of how multiple overlapping fire events spatially relate to each other (Figure 1d; Table S3). The spatial patterns of fire provide important information on where fire has spread, where it has not, and the spatial variation in severity. For example, the concept of fire refugia describes areas burned at very low severity or totally unburned within a fire event (Krawchuk et al., 2020; Meddens et al., 2018). One critical ecological value of fire refugia can be as a seed source for wind-dispersed species that are killed by fire. Spatial attributes of fire(s) are important in shaping the impact of energetic and temporal attributes of fire (Table S3; Gill et al., 2022). For example, if the dimensions of patches exposed to short-interval high severity fire are small relative to a plant's seed dispersal distance, and mature individuals persist within neighbouring fire refugia, post-fire recruitment may be rapid, diminishing the impact of the short-interval fires (Figure 2d; Haire & McGarigal, 2010; Harvey et al., 2023). Similarly, insufficient fire refugia may reduce the capacity for endozoochorous (animal-dispersed) plants to disperse (Barlow & Peres, 2008), particularly in tropical ecosystems where endozoochory is common, as large and uniform fires can reduce the movement and survival of vertebrate species (Davies et al., 2023; Peres et al., 2003). Spatial scale (grain, extent) of the fire mosaic can determine the magnitude of impact that other fire attributes have on ecosystems and their biota. Identifying how spatial attributes interact with energetic and temporal attributes of fire regimes to affect ecologically important mechanisms will help focus fire ecology research (Table S3).

It is important to note that terminology related to fire continues to develop and that the intertwined relationship between different fire regime attributes and fire metrics (Buonanduci et al., 2023) can cause ambiguity in definitions. A clear example is the term 'megafire', which has been used to describe various spatial and energetic patterns of fire—from the original use of the term to mean spatially large fire events (at a variety of defined sizes; Stoof et al., 2024), to the quantity of smoke pollution produced through a series of fire events (Linley et al., 2022). Recent debates have pushed for consistent definition of megafires as strictly spatial—namely to fires over 10,000 ha in size—to avoid ambiguity (Linley et al., 2022, 2025). Similarly, pyrodiversity is often used to describe the overarching variation in landscape patterns of fire (Jones & Tingley, 2021). It can vary from simple characterisation of the variation in fire events, disconnected from population processes, to more concrete quantifications of the types of patterns of fire that support different biotic processes and species (Senior et al., 2021). For pyrodiversity, we encourage the consideration of how the variation in fire relates to the processes of interest at various spatial and temporal scales (Steel et al., 2024), and description of explicit metrics related to this variation (e.g. proportion of area burnt at different time since fires). Like with the term 'biodiversity', there are many important metrics and factors to include (e.g. species richness, alpha diversity, beta diversity) and being clear in our use of the term is critical. Explicitly defining metrics that relate to the ecological mechanism studied thus provides the best chance of identifying and communicating accurate and ecologically robust relationships between fire and biota.

4 | HOW DO WE TIE ALL OF THIS TOGETHER?

In the context of plants, we have presented examples of processes and mechanisms that are typically explored within the field of fire ecology. In Tables S1–S3, we suggest in more detail how fire metrics could be used to explore how fire relates to different kinds of ecological processes, some of the relevant traits that may determine change, suggested applications and challenges in interpretation. We posit that carefully considering the ecological processes of interest will help to identify important intersections between these different fire metrics in driving ecological change. Explicitly communicating the selection of fire metrics and their rationale will allow individuals to be precise in their own research, to clearly understand and connect to the work of others, and to provide the best chance of detecting and understanding fire-related impacts in a time of rapid global change.

Major challenges lie ahead as climatic change, along with other human-driven processes, shifts fire regimes and socio-ecological systems across the world. The international community of researchers and practitioners must leverage knowledge from around the globe to meet these challenges and a shared language based on ecological processes can help disentangle complexity. We acknowledge that it is not always easy to define, calculate and interpret fire metrics and that there are many ways to do so. Given this, we do not prescribe methods for the vast possibilities in defining fire metrics. We do, however, suggest that fire metrics should be carefully considered and explained by authors, so that readers can understand the justification for one metric over another. Desirable information may not always be available, and if relevant, this should be acknowledged when this is the case. Concise language and simple terminology may be preferable to aid in communication. But that simple terminology needs to hold sufficient information to provide context. Emerging concepts, such as pyrodiversity, are important, and related metrics trying to quantify the essence of the concept should be clearly defined. We have presented a few examples of where language could be a barrier to shared knowledge, and how promoting and applying intentional use of fire-related language will increase comparability and interpretability among studies from ecosystems around the world. We have emphasised the use of ecological mechanisms to build a shared and comparative understanding of fire-related change across ecosystems and biota. We reason that this same thinking, through the lens of mechanisms of change, will enable the application of fire measures to other objects of study, such as fuel, fauna, microclimate, waterways and access to culturally important resources.

AUTHOR CONTRIBUTIONS

Ella Plumanns-Pouton, Sarah C. McColl-Gausden, Luke Collins, Brian J. Harvey and Meg A. Krawchuk conceived of and contributed conceptually to the perspective. Ella Plumanns-Pouton and Sarah C. McColl-Gausden led the writing of the manuscript. All authors wrote, edited and contributed critically to several drafts.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

No data were used.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1. Metrics of the energetic attributes of fire and their definitions, relevant mechanisms of study, important traits, suggested applications, interpretations and challenges, and case studies.

Table S2. Metrics of the temporal attributes of fire and their definitions, relevant mechanisms of study, important traits, suggested applications, interpretations and challenges, and case studies.

Table S3. Metrics of the spatial attributes of fire and their definitions, relevant mechanisms of study, important traits, suggested applications, interpretations and challenges, and case studies.

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