Received: 28 August 2023 | Accepted: 29 August 2023

DOI: 10.1111/1365-2435.14432

Functional Ecology | BRITISH ECOLOGICAL SOCIETY

RESEARCH HIGHLIGHT

Fire, flammability and functional traits at the forefront of global change ecology

Rachel M. Mitchell[1] | Adam R. Martin[2]

[1]School of Natural Resources and the Environment, University of Arizona, Tucson, Arizona, USA

[2]Department of Physical and Environmental Sciences, University of Toronto Scarborough, Toronto, Ontario, Canada

Correspondence
Rachel M. Mitchell
Email: rachelmm@arizona.edu

Funding information
Natural Sciences and Engineering Research Council of Canada

Handling Editor: Katie Field

Vegetation fires—a term encompassing wildfires, biomass burning, forest fires and scrub fires, among others (Bowman et al., 2020)—have played a key role in governing Earth's systems for millions of years, dating to the evolution of vascular plants during the Silurian Period some 420 million years ago (Scott & Glasspool, 2006). Fire also remains among the most critical factors shaping the structure, function and composition of "neoecological" landscapes worldwide, with roughly 3–5 million km^2 of forests, savannas, grasslands and shrublands—the latter being the focus of the research by Boving et al. (2023)—burned annually (Chuvieco et al., 2018). Fires are central in multiple terrestrial-atmospheric feedback cycles. For example, fires contribute ~8 billion tonnes of CO_2 emissions annually and reducing in Earth's vegetation biomass by ~10% annually. These emissions and reductions that are partially offset by post-fire vegetation regrowth, are estimated to store ~7 billion tonnes of CO_2 annually (Lasslop et al., 2020). At the same time, fire has shaped Earth's biodiversity across evolutionary timescales and continues to structure the composition and dynamics in many of Earth's present-day ecological communities (Kelly et al., 2020).

However, Earth's fire regimes are shifting drastically throughout the Anthropocene. On account of complex interactions among global environmental change, shifting land-uses, human pressures and changes in species' biogeography, the frequency, intensity and distribution of fire-prone areas on Earth is in flux (Jones et al., 2022; Pausas & Keeley, 2021). As the world's climate warms and precipitation patterns change, predictions and observations show prolonged fire seasons (Cattau et al., 2020), altered fire regimes (Balch et al., 2022) and higher severity of burning (Grünig et al., 2023). Taken together, understanding the complex and multi-scale pathways through which fire governs the structure and function of Earth's ecosystems is clearly of tremendous scientific importance.

Our understanding of vegetation fires is underpinned by interdisciplinary science focused on fire behaviour (e.g. Sullivan, 2017a 2017b), modelling (e.g. Hantson et al., 2016), mapping (e.g. Andela et al., 2019), reconstruction (e.g. Ryzhkova et al., 2020) and management (e.g. Martell, 2015). Functional ecology also plays an important role in this endeavour, by identifying the key traits that govern plant species'—and by extension larger landscape-scale—susceptibility and responses to burning. Indeed, multiple studies have tested hypotheses related to how fire has at least partially shaped certain plant functional traits associated with above- and below-ground reproduction strategies, resprouting ability, self-pruning and bark (summarised by Bowman et al., 2009), and how these traits scale-up to influence landscape level fire risk.

Leaf-level traits are also a prominent focus within the fire ecology literature, particularly within the nascent subdiscipline of "pyro-ecophysiology": an interdisciplinary area that merges fire and functional ecology (Jolly & Johnson, 2018), in which Boving et al. (2023) situate their research. In pyro-ecophysiology, "Live Fuel Moisture" (LFM) content—the ratio of leaf tissue water: dry matter content—has arguably been the most widely studied trait that is inferred to govern species- and landscape-level fire risk. Specifically, LFM is associated

[Correction added on 13 November 2023, after first online publication: Handling Editor name has been updated.]

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.
© 2023 The Authors. *Functional Ecology* published by John Wiley & Sons Ltd on behalf of British Ecological Society.

with leaf hydration status being (A) negatively related to ignitability and combustibility, and therefore (B) widely used to categorise flammability at multiple spatial scales (Chuvieco et al., 2004; Yebra et al., 2013). Although LFM content is well-understood as a key trait in fire ecology and management sciences (Jolly & Johnson, 2018), its explicit relationship with flammability and other plant life-history traits is less well-explored. As Boving et al. (2023) explain, efforts to consolidate flammability trait databases for plants globally have only recently begun (Popović et al., 2021), and to our knowledge, flammability traits have only tangentially been incorporated into analyses of plant form and function (Li et al., 2022).

The work by Boving et al. (2023) aims to address these and other research gaps, by weaving a narrative that incorporates elements of fire science, pyro-ecophysiology and functional ecology. Specifically, the research presented by Boving et al. (2023) employs lab-based dehydration experiments conducted on two model chaparral shrub species (*Adenostoma fasciculatum*, *Ceanothus megacarpus*), to test hypotheses on how LFM content and drought tolerance traits (i.e. turgor loss point) directly correlate to flammability, measured in their study as a multivariate combination of ignitability, combustibility, consumability and flame duration. Boving et al. (2023) also take the opportunity to address interesting themes of threshold responses in trait-function relationships: a concept widely understood in conservation and biodiversity science (Huggett, 2005) but less well developed in the functional trait ecology literature. Specifically, Boving et al. (2023) provide a compelling analysis designed to test if flammability changes abruptly at certain LFM content values, thereby aiming to inform predictions of fire risk under shifting environmental conditions.

Boving et al. (2023) provides several intriguing findings that advance our understanding of trait-based flammability, in a manner that is applicable to pressing needs in fire ecology. First, they reveal management-relevant axes of flammability trait variation for the two study species that are strongly influenced by tissue moisture (and by extension, drought tolerance traits). As climate and fire regimes change, there has been a push to incorporate these types of physiological response traits into global-scale fire risk and behaviour models (Dickman et al., 2023).

Boving et al. (2023) then demonstrate how their "ignitability-combustibility" proxy is linearly correlated to leaf water potentials. In doing so, the authors begin to disentangle the physiological mechanisms that govern an inter- and intraspecific axis of trait variation related to flammability that exists among co-occuring species. However, their segmented regression analysis shows that LFM content, a metric more commonly measured in management settings and incorporated into fire risk and behaviour models, exhibits a threshold-like relationship with flammability: as individuals reached their turgor loss point, flammability increases. These findings suggests that wildfire at the landscape level may be driven in part by individual plant responses to prevailing water availability conditions and their underlying physiological mechanisms.

Understanding the relationships between leaf traits and flammability is an emerging area of inquiry in the field of functional trait ecology, and the novel findings revealed in this paper open multiple avenues for further advances. Perhaps most saliently, exploring the ubiquity of flammability proxies like the "ignitability–combustibility" proxy across more species—especially those in fire-prone regions and biomes—would reveal whether or not species exhibit universal correlations between physiological function, life-history strategies, and flammability traits. From a practical perspective, this line or research would enhance scientists' and practitioners' ability to rapidly monitor and characterise flammability.

One shortcoming highlighted by Boving et al. (2023) is the lack of simultaneous measurements of LFM content and plant tissue water potential, hampering our ability to advance pyro-ecophysiology. This is largely because quantifying turgor loss point (for example) requires significant investments of time and specialised equipment. Yet recent advances in high-throughput approaches to turgor loss point estimation (Bartlett et al., 2012)—usually employed in the rapid screening of tree and crop species' drought tolerance—might well find a novel application in the pyro-ecology literature. At the same time, further exploring relationships between more easily measured plant traits (e.g. leaf dry matter content and specific leaf area) and turgor loss point across species, might broaden the ability of researchers to collect these metrics simultaneously. In doing so, the type of research conducted by Boving et al. (2023) appears poised to broaden the applicability of major themes in functional ecology—including the consolidation of large global plant trait databases (Kattge et al., 2020) and analyses of plant trait spectra (Díaz et al., 2016)—to the world of fire science.

AUTHOR CONTRIBUTIONS

Rachel M. Mitchell and Adam R. Martin co-led conception of the commentary, as well as the writing and revisions of the manuscript. Both authors gave final approval for publication.

ACKNOWLEDGMENTS

We are grateful to Katie Field for providing constructive feedback on an earlier draft of this commentary.

FUNDING INFORMATION

Adam R. Martin is supported by a Discovery Grant from the Natural Sciences and Engineering Research Council of Canada.

CONFLICT OF INTEREST STATEMENT

Adam Martin is an Associate Editor of *Functional Ecology*, and Rachel Mitchell is a peer reviewer for *Functional Ecology* on Boving et al. (2023). Neither took no part in the peer review and decision-making processes for this paper. The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

None.

ORCID

Rachel M. Mitchell https://orcid.org/0000-0002-0867-9068
Adam R. Martin https://orcid.org/0000-0002-7207-4004

REFERENCES

Andela, N., Morton, D. C., Giglio, L., Paugam, R., Chen, Y., Hantson, S., Van Der Werf, G. R., & Randerson, J. T. (2019). The global fire atlas of individual fire size, duration, speed and direction. *Earth System Science Data*, *11*, 529–552.

Balch, J. K., Abatzoglou, J. T., Joseph, M. B., Koontz, M. J., Mahood, A. L., McGlinchy, J., Cattau, M. E., & Williams, A. P. (2022). Warming weakens the night-time barrier to global fire. *Nature*, *602*, 442–448.

Bartlett, M. K., Scoffoni, C., Ardy, R., Zhang, Y., Sun, S., Cao, K., & Sack, L. (2012). Rapid determination of comparative drought tolerance traits: Using an osmometer to predict turgor loss point. *Methods in Ecology and Evolution*, *3*, 880–888.

Boving, I., Celebrezze, J., Salladay, R., Ramirez, A., Anderegg, L., & Moritz, M. (2023). Live fuel moisture and water potential exhibit differing relationships with leaf-level flammability thresholds. *Functional Ecology*.

Bowman, D. M., Balch, J. K., Artaxo, P., Bond, W. J., Carlson, J. M., Cochrane, M. A., D'Antonio, C. M., DeFries, R. S., Doyle, J. C., & Harrison, S. P. (2009). Fire in the earth system. *Science*, *324*, 481–484.

Bowman, D. M., Kolden, C. A., Abatzoglou, J. T., Johnston, F. H., van der Werf, G. R., & Flannigan, M. (2020). Vegetation fires in the Anthropocene. *Nature Reviews Earth & Environment*, *1*, 500–515.

Cattau, M. E., Wessman, C., Mahood, A., & Balch, J. K. (2020). Anthropogenic and lightning-started fires are becoming larger and more frequent over a longer season length in the USA. *Global Ecology and Biogeography*, *29*, 668–681.

Chuvieco, E., Cocero, D., Riano, D., Martin, P., Martınez-Vega, J., De La Riva, J., & Pérez, F. (2004). Combining NDVI and surface temperature for the estimation of live fuel moisture content in forest fire danger rating. *Remote Sensing of Environment*, *92*, 322–331.

Chuvieco, E., Lizundia-Loiola, J., Pettinari, M. L., Ramo, R., Padilla, M., Tansey, K., Mouillot, F., Laurent, P., Storm, T., & Heil, A. (2018). Generation and analysis of a new global burned area product based on MODIS 250 m reflectance bands and thermal anomalies. *Earth System Science Data*, *10*, 2015–2031.

Díaz, S., Kattge, J., Cornelissen, J. H., Wright, I. J., Lavorel, S., Dray, S., Reu, B., Kleyer, M., Wirth, C., & Colin Prentice, I. (2016). The global spectrum of plant form and function. *Nature*, *529*, 167–171.

Dickman, L. T., Jonko, A. K., Linn, R. R., Altintas, I., Atchley, A. L., Bär, A., Collins, A. D., Dupuy, J. L., Gallagher, M. R., & Hiers, J. K. (2023). Integrating plant physiology into simulation of fire behavior and effects. *New Phytologist*, *238*, 952–970.

Grünig, M., Seidl, R., & Senf, C. (2023). Increasing aridity causes larger and more severe forest fires across Europe. *Global Change Biology*, *29*, 1648–1659.

Hantson, S., Arneth, A., Harrison, S. P., Kelley, D. I., Prentice, I. C., Rabin, S. S., Archibald, S., Mouillot, F., Arnold, S. R., & Artaxo, P. (2016). The status and challenge of global fire modelling. *Biogeosciences*, *13*, 3359–3375.

Huggett, A. J. (2005). The concept and utility of 'ecological thresholds' in biodiversity conservation. *Biological Conservation*, *124*, 301–310.

Jolly, W. M., & Johnson, D. M. (2018). Pyro-ecophysiology: Shifting the paradigm of live wildland fuel research. *Fire*, *1*, 8.

Jones, M. W., Abatzoglou, J. T., Veraverbeke, S., Andela, N., Lasslop, G., Forkel, M., Smith, A. J., Burton, C., Betts, R. A., & van der Werf, G. R. (2022). Global and regional trends and drivers of fire under climate change. *Reviews of Geophysics*, *60*, e2020RG000726.

Kattge, J., Bönisch, G., Díaz, S., Lavorel, S., Prentice, I. C., Leadley, P., Tautenhahn, S., Werner, G. D., Aakala, T., & Abedi, M. (2020). TRY plant trait database–enhanced coverage and open access. *Global Change Biology*, *26*, 119–188.

Kelly, L. T., Giljohann, K. M., Duane, A., Aquilué, N., Archibald, S., Batllori, E., Bennett, A. F., Buckland, S. T., Canelles, Q., & Clarke, M. F. (2020). Fire and biodiversity in the Anthropocene. *Science*, *370*, eabb0355.

Lasslop, G., Hantson, S., Harrison, S. P., Bachelet, D., Burton, C., Forkel, M., Forrest, M., Li, F., Melton, J. R., & Yue, C. (2020). Global ecosystems and fire: Multi-model assessment of fire-induced tree-cover and carbon storage reduction. *Global Change Biology*, *26*, 5027–5041.

Li, J., Chen, X., Niklas, K. J., Sun, J., Wang, Z., Zhong, Q., Hu, D., & Cheng, D. (2022). A whole-plant economics spectrum including bark functional traits for 59 subtropical woody plant species. *Journal of Ecology*, *110*, 248–261.

Martell, D. L. (2015). A review of recent forest and wildland fire management decision support systems research. *Current Forestry Reports*, *1*, 128–137.

Pausas, J. G., & Keeley, J. E. (2021). Wildfires and global change. *Frontiers in Ecology and the Environment*, *19*, 387–395.

Popović, Z., Bojović, S., Marković, M., & Cerdà, A. (2021). Tree species flammability based on plant traits: A synthesis. *Science of the Total Environment*, *800*, 149625.

Ryzhkova, N., Pinto, G., Kryshen, A., Bergeron, Y., Ols, C., & Drobyshev, I. (2020). Multi-century reconstruction suggests complex interactions of climate and human controls of forest fire activity in a Karelian boreal landscape, North-West Russia. *Forest Ecology and Management*, *459*, 117770.

Scott, A. C., & Glasspool, I. J. (2006). The diversification of Paleozoic fire systems and fluctuations in atmospheric oxygen concentration. *Proceedings of the National Academy of Sciences of the United States of America*, *103*, 10861–10865.

Sullivan, A. L. (2017a). Inside the inferno: Fundamental processes of wildland fire behaviour: Part 1: Combustion chemistry and heat release. *Current Forestry Reports*, *3*, 132–149.

Sullivan, A. L. (2017b). Inside the inferno: Fundamental processes of wildland fire behaviour: Part 2: Heat transfer and interactions. *Current Forestry Reports*, *3*, 150–171.

Yebra, M., Dennison, P. E., Chuvieco, E., Riaño, D., Zylstra, P., Hunt, E. R., Jr., Danson, F. M., Qi, Y., & Jurdao, S. (2013). A global review of remote sensing of live fuel moisture content for fire danger assessment: Moving towards operational products. *Remote Sensing of Environment*, *136*, 455–468.

How to cite this article: Mitchell, R. M., & Martin, A. R. (2023). Fire, flammability and functional traits at the forefront of global change ecology. *Functional Ecology*, *37*, 2767–2769. https://doi.org/10.1111/1365-2435.14432