Guo *Ecological Processes* (2021) 10:43
https://doi.org/10.1186/s13717-021-00320-6

Ecological Processes

LETTER Open Access

Using "management mosaics" to mitigate the impacts from extreme wildfires

Qinfeng Guo

Abstract

Human activities and global change have resulted in more severe and destructive megafires in forest ecosystems worldwide. Here, I introduce and discuss the concept of "management mosaics" and how to use it over both space and time to mitigate the growing impacts of extreme wildfires.

Keywords: Disturbance refuges, Fire frequency and severity, Fuel treatment, Human activities, Megafires

Human activities have increasingly caused more catastrophic and destructive megafires across various types of forest ecosystems (Fig. 1) (Peters et al. 2004). To respond to this trend in managed forest ecosystems especially at the wildland-urban interface (WUI), one of the common approaches to date has been fuel treatments (Keeley 2006). Here, in this letter, I briefly discuss a key topic in fuel treatments, i.e., the "management mosaics" which involves diverse treatment techniques and could even include untreated ("control") patches over space and time (see details below). To avoid or reduce the damage from catastrophic forest fires, common management practices tend to keep fire severity at low to intermediate levels. Nonetheless, while most extreme fires are indeed harmful and need to be avoided, historical evidence suggests that some large fires are part of the natural process and could be beneficial to ecosystem health. When extreme fires do occur, management mosaics could maintain or create "disturbance refugia", thus helping us to reach our management goals (Brown et al. 2004; Krawchuk et al. 2020; Sedell et al. 1990).

In some managed forest ecosystems, practices are commonly aimed at reducing fuels to avoid large and severe fires. However, I would argue that management need not always target fuel reduction and some large even more rare extreme fires (i.e., total destruction of existing stands) could be allowed to occur but kept at a lower frequency (e.g., the level without human influences) and in well contained (e.g., with well-established fire breaks), remote (to human infrastructures), and/or isolated areas. This is in part because some large and severe fires are beneficial to nutrient cycling, overall ecosystem health, and long-term sustainability. The distribution of fires based on either size or severity must be balanced, to follow as much as possible the natural frequency distribution such as the universal rank-size distribution, a rule similar to the Zipf's law (Zipf 2016). That is, the overall fire spectrum includes many small and less severe fires and a few very large and severe ones to resemble a roughly smooth order over space (landscape) at a given time or over time (e.g., 10–100 years) in a habitat (Fig. 1) (Guo 2003; Castorani and Baskett 2020).

In many semi-natural and managed forest ecosystems, to avoid catastrophic megafires, "fuel treatments" need to adopt the "management mosaics" approach across the target landscapes (Pastur et al. 2020), something similar to "intercropping" used to promote agricultural productivity and mitigation of drastic environmental changes (Vandermeer 1992). In other words, different treatments (e.g., thinning, prescribed burning and grazing, fuel breaks, clear-cutting, or their combination as mixed treatments) could be used in the same areas (or patches) but in different years (temporal turnover) or in different patches but in the same year (spatial turnover). First, highly diversified management mosaics could reduce the risk of failed management as a certain type of treatment

Correspondence: qinfeng.guo@usda.gov
USDA FS, Eastern Forest Environmental Threat Assessment Center, 3041 Cornwallis Road, Research Triangle Park, NC 27709, USA

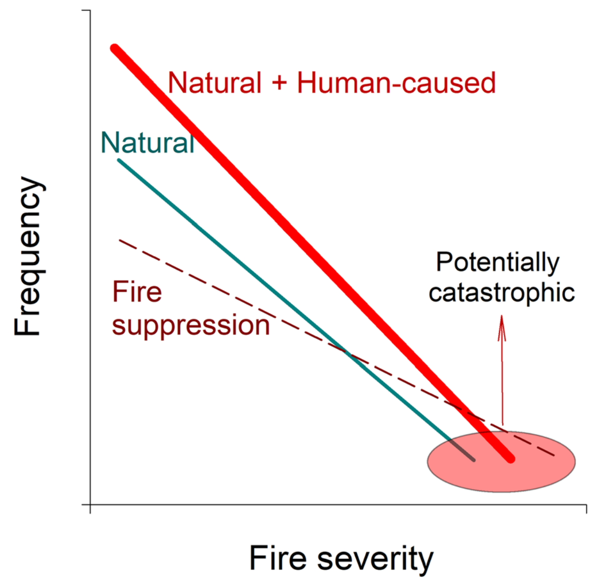

Fig. 1 A model showing various frequency distributions (log) of fire severity or size (log rank order) in nature vs. under growing human activities based on Zipf's Law. In many ecosystems, small and less severe fires are numerous but large and highly severe ones are few; that is, the frequency distribution of fire intensity (severity) or size usually follow the Zipf's Law. Human activities increase the probability of fire, but total fire suppression usually reduces the occurrence of naturally occurring small- and middle-sized fires and could increase the risk of unintended catastrophic fires due to a large amount of accumulated fuels

may not work well at a particular site or in a particular year. Second, it could increase habitat spatial-temporal heterogeneity so it can help maintain or even promote biodiversity. Third, it could reduce the rate of wildfire spread, better resist nonnative species invasions, and lead to higher productivity (carbon sequestration) and stability (Isbell et al. 2015). For example, fuel removal by prescribed fire could first target the forest patches with sudden insect/pathogen infestations so it can reduce the forest damaged by diseases. Fourth, diverse "fuel treatments" could buffer climate change effects and possible disruptions due to extraordinary events such as massive insect outbreaks through "dilution and isolation effects" (Guo et al. 2019; Schmidt and Ostfeld 2001). Finally, different treatments of fuel removal and their optimal combinations could produce isolated forest patches with little fuel to burn, thus reducing the speed of fire spread.

It is worth pointing out that it is more straightforward to apply the concept of management mosaics in the spatial layout of different fuel treatments. In the future, its temporal dimension (a stronger temporal turnover of different treatments) should also be given a priority. Ideally, the spatial-temporal treatment combinations (e.g., both spatial and temporal layouts of different fuel treatments across a landscape) should be recommended. Planning fuel reduction could also make better use of short-term (e.g., seasonal) weather forecasting and climate modeling that are constantly being improved so that more fuels could be removed before fire seasons during exceptionally dry years than in wet years. Unfortunately, the lack of personnel and funding often severely limits our management efforts.

Increased fire frequency due to the contribution from human-induced burns may promote the invasion of nonnative species, many of which are highly flammable (Fusco et al. 2019). In contrast, total fire suppression could reduce the carbon sequestration rate, but increase unstable carbon stock that eventually leads to much more catastrophic megafires in the future (Hurteau and Brooks 2011). Some "complete burns" with longer intervals also occur in some natural ecosystems, such as natural forests. Allowing the occurrence of less catastrophic or extreme burns, which could include ground, surface, and crown fires in relatively small and isolated areas with well-established fire breaks (i.e., the "controlled extreme fires"), would enable healthy forest communities to complete their natural cycles of succession, i.e., completing full nutrient retention and species replacement (Pickett et al. 1987). This is needed because some species (e.g., some trees with large seeds) need such large fires (e.g., high heat) to reemerge (germinate), with other organisms such as animals and microorganisms, benefiting as well. The key is to ensure that the burned and surrounding habitats are well-protected disturbance refugia within mosaics of forest fires, droughts, and insect outbreaks so the burned patches can recover faster with the mixture of re-colonizers, re-sprouters, and reseeders (Krawchuk et al. 2020).

Adaptive fire management needs to carefully consider the short- and long-term goals, consequences, and implications and make timely adjustments in responding to increasing human activities and climate change. To reach the long-term goals of ecosystem sustainability, more theoretical, field, and experimental research on management mosaics are needed.

Acknowledgements
I thank several colleagues particularly D. Brockway and G. Nunez Mir, and two anonymous reviewers for helpful comments. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Author's contributions
QG wrote the manuscript. The author read and approved the final manuscript.

Funding
Not applicable

Availability of data and materials
Not applicable

Declarations

Ethics approval and consent to participate
Not applicable

Consent for publication
Not applicable

Competing interests
The author declares no competing interests.

Received: 11 January 2021 Accepted: 7 June 2021
Published online: 19 June 2021

References

Brown RT, Agee JK, Franklin JF (2004) Forest restoration and fire: principles in the context of place. Conserv Biol 18(4):903–912. https://doi.org/10.1111/j.1523-1739.2004.521_1.x
Castorani MC, Baskett ML (2020) Disturbance size and frequency mediate the coexistence of benthic spatial competitors. Ecology 101:e02904
Fusco EJ, Finn JT, Balch JK, Nagy RC, Bradley BA (2019) Invasive grasses increase fire occurrence and frequency across US ecoregions. Proc Nat Acad Sci USA 116(47):23594–23599. https://doi.org/10.1073/pnas.1908253116
Guo Q (2003) Disturbance, life history, and optimal management for biodiversity. Ambio 32(6):428–430. https://doi.org/10.1579/0044-7447-32.6.428
Guo Q, Fei S, Potter KM, Liebhold AM, Wen J (2019) Tree diversity regulates forest pest invasion. Proc Nat Acad Sci USA 116(15):7382–7386. https://doi.org/10.1073/pnas.1821039116
Hurteau MD, Brooks ML (2011) Short- and long-term effects of fire on carbon in US dry temperate forest systems. Bioscience 61(2):139–146. https://doi.org/10.1525/bio.2011.61.2.9
Isbell F, Craven D, Connolly J, Loreau M, Schmid B, Beierkuhnlein C, Bezemer M, Bonin C, Bruelheide H, De Luca E, Ebeling A, Griffin J, Guo Q, Hautier Y, Hector A, Jentsch A, Kreyling J, Lanta V, Manning P, Meyer S, Mori A, Naeem S, Niklaus P, Polley H, Reich P, Roscher C, Seabloom E, Smith M, Thakur M, Tilman D, Tracy B, van der Putten W, van Ruijven J, Weigelt A, Weisser W, Wilsey B, Eisenhauer N (2015) Biodiversity increases the resistance of ecosystem productivity to climate extremes. Nature 526(7574):574–577. https://doi.org/10.1038/nature15374
Keeley JE (2006) Fire management impacts on invasive plants in the western United States. Conserv Biol 20(2):375–384. https://doi.org/10.1111/j.1523-1739.2006.00339.x
Krawchuk M, Meigs G, Cartwright J, Coop J, Davis R, Holz A, Kolden C, Meddens A (2020) Disturbance refugia within mosaics of forest fire, drought, and insect outbreaks. Front Ecol Environ 18(5):235–244. https://doi.org/10.1002/fee.2190
Pastur GJM, Vanha-Majamaa I, Franklin JF (2020) Ecological perspectives on variable retention forestry. Ecol Process 9:12. https://doi.org/10.1186/s13717-020-0215-3
Peters DP, Pielke RA, Bestelmeyer BT, Allen CD, Munson-McGee S, Havstad KM (2004) Cross-scale interactions, nonlinearities, and forecasting catastrophic events. Proc Nat Acad Sci USA 101(42):15130–15135. https://doi.org/10.1073/pnas.0403822101
Pickett S, Collins S, Armesto JJ (1987) Models, mechanisms and pathways of succession. Bot Rev 53(3):335–371. https://doi.org/10.1007/BF02858321
Schmidt KA, Ostfeld RS (2001) Biodiversity and the dilution effect in disease ecology. Ecology 82(3):609–619. https://doi.org/10.1890/0012-9658(2001)082[0609:BATDEI]2.0.CO;2
Sedell JR, Reeves GH, Hauer FR, Stanford JA, Hawkins CP (1990) Role of refugia in recovery from disturbances: Modern fragmented and disconnected river systems. Environ Manage 14(5):711–724. https://doi.org/10.1007/BF02394720
Vandermeer JH (1992) The ecology of intercropping. Cambridge University Press, Cambridge
Zipf GK (2016) Human behavior and the principle of least effort: An introduction to human ecology. Addison-Wesley Press, Cambridge, Mass

Publisher's Note