A physiological understanding of organismal responses to fire

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Short summary:
Stawski and Doty discuss the need for more research on how individual organisms respond physiologically to fire in order to develop more effective fire management strategies that conserve a greater number of species.

Main text:
Devastation of both natural and human habitats due to wildfires is becoming an increasingly prevalent global issue. Fire-adapted and fire-prone regions, such as California and parts of Australia, are experiencing more frequent and increasingly destructive wildfires, accompanied by longer wildfire seasons. Wildfires are further becoming more commonplace in areas that historically do not regularly experience fire, causing an increased risk of habitat loss in less resilient ecosystems. The escalation of fire outbreaks is a result of several factors; however, at the forefront of these outbreaks is an increase in highly flammable dry vegetation due to sustained drought, a trend we will see growing in our changing climate. To mitigate the potentially detrimental outcomes of wildfires, it is imperative that we understand the response of ecosystems to fire not only from an ecological perspective, but also from a physiological perspective. Research focused on the physiological adaptations of organisms to environmental constraints caused by fire can give insight into how plants and animals respond to fire, on both short- and long-term scales. Importantly, this information needs to be adapted effectively into fire management plans to improve the recovery success of organisms after fire.

Many recent studies on the conditions that promote fire have provided further evidence for the impact of climate change and habitat degradation on an increase in fire events. In addition to warmer temperatures contributing to the ignition of more fires, a decrease in rain events throughout the year and especially during the fire season also has an impact on wildfire trends [1]. The expanding human population is also inadvertently contributing to wildfires; for example, urban areas that are constructed adjacent to natural areas often contribute to an enhanced risk of fire from sources such as improperly tended human-made fires or even dropping a lit cigarette [2]. Further, as human settlements expand into increasing proximity with natural areas, wildfires must be extinguished before they damage property and lives; however, such human intervention interferes with normal fire regimes and may ultimately lead to large and uncontrollable fires.

Some data and ideas are already emerging describing methods to combat an increase in irregular wildfires. One recommendation, proposed from simulation experiments employing data from the Sierra Nevada mountain range in the United States, is to implement restoration treatments [3]; this involves returning to natural historical fire regimes. Such treatments would likely allow fire-adapted regions to recover and also to avoid the build-up of highly flammable vegetation that leads to uncontrollable and destructive fires. Indeed, an evaluation of wildfires that have occurred in California from 1984-2015 revealed that areas which have implemented management burns have experienced a smaller increase in high-severity fires in comparison to areas without such treatments [4]. However, while these management burns appear effective on a large-scale, we need to understand the effects of these plans at the individual organismal level in order to make appropriate decisions for when management burns should occur and how they should be implemented. Further, an integrative approach to understand fire effects on plants and animals necessitates a collaborative effort between scientists from different fields; if some are able to obtain physiological data at the individual level and others ecological data at the population level, together we can use these data to develop more robust management policies that can preserve both natural and human communities.

Notably, it will be difficult to develop a management plan that will benefit every organism in a community. Previous studies have revealed that there are variations in the way species respond to fires; for example, some plants need regular fires to germinate whereas other plants face difficulties in re-sprouting after a fire [5]. Physiological research can aid in understanding the dynamics of population response by revealing the conditions needed for each species to thrive, the physiological mechanisms species employ to survive fire, and how organisms use energy in response to an altered habitat. For instance, the water potential, growth, and stomatal conductance of three plant species endemic to Santa Catalina Island were found to differ in the first dry season following a fire [6]. These differences in the species' physiological responses to water limitation may have implications for the abundance and distribution of plants in dry or post-fire conditions. Therefore, it is vital to consider physiological responses in relation to the timing of management burns and the extent and intensity of the fire in relation to current environmental conditions.

Management burns are typically conducted during winter, as cooler conditions generally make fires more manageable. However, complications may arise for the many mammalian and avian species that employ torpor (a temporal reduction in metabolic rate and body temperature) during winter in response to a decrease in temperature and resource availability. While some torpid mammals are able to respond to fire cues such as smoke, their responses are often slowed at colder temperatures [7]. Therefore, these torpid animals would be at risk of mortality during winter management burns conducted at very cold temperatures, as they would be less likely to rewarm from torpor and escape. Studies conducted in Australia also revealed that some small terrestrial mammals become energetically constrained even after mild fires that only reduce ground cover and understorey vegetation [7]. Conversely, some bats are less energetically constrained as they are able to take advantage of the more open foraging conditions. Consequently, large-scale fire management strategies require an integral understanding of the physiological responses to fire from a range of organisms under different scenarios; such data will help to create informed policy decisions that promote the preservation of biodiversity.

An important area of fire research that can primarily be addressed via physiological studies is the impact of smoke on the health of ecosystems. Smoke from fire deteriorates air quality and is not only of concern to animals and plants, but also to human health. Smoke inhalation can result in respiratory issues such as asthma and chronic obstructive pulmonary disease and can often lead to death. Hazardous smoke from fires is known to affect orangutans, a species that is already negatively impacted by habitat loss from palm oil plantations. Orangutans exposed to smoke reduce activity and may be required to enhance their immune response to deal with smoke inhalation [8]. The observed increase in resting time, the decrease in the time spent travelling and the energy needed to activate the immune response would inevitably lead to a negative energy balance and likely a further loss of individuals.

While large-scale ecological and modelling research is crucial to our understanding of fire, we also need to interpret, on a smaller scale, how the basic physiology of flora and fauna respond to fire events. Because surviving organisms are faced with a lack of food and water resources, an increase in opportunistic predators, and a shortage of safe refuges in which to hide [9], it is vital to know the physiological responses of individuals to these conditions in order to understand the impacts of differing fire regimes. Such research is undoubtedly challenging as fire events are unpredictable, leading to difficulty in collecting data prior to fire. Promisingly, many research stations and agencies conduct experimental and management burns in numerous countries. Researchers can take advantage of these burns to ensure they obtain a robust data set, including before and after a fire and in nearby control areas, as has been done recently in Australia [7].

Fires are a necessary and vital part of many environments, but at the moment they have become largely destructive. We need more collaborative work and funding into the physiological responses of flora and fauna to fire in order to manage fire regimes effectively; particularly in North America, Australia, Russia, China and South Asia, where approximately 50% of tree cover loss is a direct result of wildfires [10]. Better fire management practices could not only decrease this unnatural loss of forests, but also alleviate the negative consequences of wildfires while still maintaining a natural fire regime for those species that are reliant on fire.

Author contributions:
C.S. and A.D. devised and discussed the original idea for the manuscript. C.S. wrote the first draft and both authors contributed extensively to the writing of further drafts.

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