The evolution of human-driven fire regimes in Africa

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Human ability to manipulate fire and the landscape has increased over evolutionary time, but the impact of this on fire regimes and consequences for biodiversity and biogeochemistry are hotly debated. Reconstructing historical changes in human-derived fire regimes empirically is challenging, but information is available on the timing of key human innovations and on current human impacts on fire. Here we incorporate this knowledge into a spatially-explicit fire propagation model. We explore how changes in population density, the ability to create fire, and the expansion of agro-pastoralism altered the extent and seasonal distribution of fire as modern humans arose and spread through Africa. Much emphasis has been placed on the positive effect of population density on ignition frequency but our model suggests this is less important than changes in fire spread and connectivity that would have occurred as humans learned to light fires in the dry season, and to transform the landscape through grazing and cultivation. Different landscapes show different limitations; we show that substantial human impacts on burned area would only have started ∼4000 BP in open landscapes, whereas they could have altered fire regimes in closed/dissected landscapes by ∼40,000 BP. Dry season fires have been the norm for the last 200-300 KY across all landscapes. The annual area burned in Africa probably peaked between 4 and 40 KYA. These results agree with recent paleo-carbon studies that suggest that the biomass burned today is less than in the recent past in sub-tropical countries.

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Fire has been a part of the earth system for billions of years (?) but recently - within the last million years at most - humans have provided a new and different source of ignition. Today fires in all ecosystems are largely started by human ignitions , whether intentionally (for land management or arson) or by accident.

From studies in modern systems we know that humans can affect fire regimes via their effects on both ignition (frequency, season, and location) and landscape connectivity. However, we lack an understanding of how these different impacts might have emerged as humans learned to control fire and as they spread throughout the globe. Moreover, the degree to which current human-ignited fire regimes differ from historical, lightning-driven regimes is largely unresolved, which complicates fire management decisions.

The question is complicated by the fact that the potential limitations on fire are various and system specific (?); and as one constraint is released, others can come into play. Thus, the number of ignitions can increase without a concomitant increase in area burned (?, ?), and responses of fire to drivers like population density can be non-linear (?). Most ecosystems in Africa are probably not ignition-limited currently; ignition rates are more than sufficient to burn the available fuel, and climate and landscape connectivity act as the main limitations on fire (?, ?, ?).

Interpreting historical human effects on fire regimes using empirical data has proved challenging. Most paleoecological studies of fire have used temporal changes in charcoal sedimentation rates to examine large-scale patterns (?, ?, ?). Difficulties arise because sedimentation rates respond not only to fire frequency, but also to the type of vegetation burned and the completeness of combustion (?); a change in vegetation or the season of burning could be misinterpreted as a change in fire frequency and vice versa. For this reason, analyses usually limit themselves to descriptive scales such as 'more biomass burning' or 'less biomass burning' e.g. (?, ?), which are difficult to relate to particular characteristics of a fire regime (?). Moreover, separating the human signal from variability caused by changes in vegetation and climate over the time periods studied is often impossible (?, ?).

Nonetheless multiproxy analyses show increases in charcoal density around 60 000 years ago as humans started to spread into more regions of the globe (?). More local analyses also link increases in charcoal to timing of human settlement (?, ?), although it is possible these changes are associated with land cover change rather than alteration of fire characteristics per se.

In African savannas there is disagreement on the extent to which humans have altered the seasonal distribution of fires (?). Currently fires occur throughout the dry season (?, ?) with very few fires (< 5 %) in the wet season. Lightning is largely absent in the dry season - being associated with convective wet-season thunderstorms and more rarely with dry storms just before the first rains. Thus a lightning-driven fire regime probably had seasonal fire distributions different from modern ones, with major effects on the size, intensity and atmospheric emissions of fires (?, ?).

The impact of humans on fire regimes depends not only on their ability to manipulate fire but on the importance of this manipulation in the face of other constraints. In reconstructing past fire regimes we therefore need to know when humans could have altered various fire characteristics (ignition frequency, timing, pattern) and the extent to which these characteristics were limiting to fire.

Here we present a modeling approach that integrates information on the physics of fire spread (?, ?, ?), the effect of humans on different components of fire spread (?, ?, ?), and the paleoecology of modern humans (?, ?, ?). We use conceptual links between a) known advances in human manipulation of fire, population growth and spread, and b) the parameters of a spatially-explicit fire propagation model, to explore the types of impacts humans could have had on fire regimes as they learned to manipulate fire, their environment, and their landscapes. We propose that this will improve our ability to

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