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Communication

Flammable Mexico

Juli G. Pausas

Centro de Investigaciones sobre Desertificación, Consejo Superior de Investigaciones Científicas (CIDE-CSIC), Valencia, Spain. Email: juli.g.pausas@uv.es

Abstract. The frequency of disturbances is an important factor contributing to the megabiodiversity of Mexico, and fire is a prominent disturbance in this region. Here I briefly summarise important aspects of fire ecology in Mexico and introduce a new book for fire science in this country: *Incendios de la vegetación* (*Vegetation fires*) by D. Rodríguez-Trejo. The book covers many fire topics including fire ecology, fire behaviour, fire management, fire history and the anthropology of fire, and provides a basis for sustainable vegetation management in the region; it also advocates for the use of fire as a management tool. The message is that the biodiversity of Mexico, and therefore its management, cannot be understood without considering fire.

Additional keywords: disturbance ecology, fire adaptations, fire ecology.

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Mexico is a megadiverse North American country (Mittermeier *et al.* 1997) with a wide range of climates (e.g. wet tropical, warm temperate, mediterranean, and arid) and a diverse topography (from 0 to 5700 m above sea level). These characteristics together with its location in the transition zone towards Central America make this land a global biodiversity hotspot with species belonging to northern (Neartic) lineages co-occurring with others from southern (Neotropical) lineages. Important factors contributing to this biodiversity are the frequent disturbances in the region where volcanoes, hurricanes, and wildfires are common, together with droughts and floods. Fires occur mainly in April–May (Fig. 1); the natural sources of ignition being lightning, especially in mountains, and volcanoes (with clear evidence of fires ignited by volcanoes, e.g. from the Popocatépetl volcano). However, currently most fires are caused by human activities, as in many other countries. Hurricanes add fuel and increase the intensity and probability of fire. The indigenous Mexican populations long ago used surface fires in a sustainable manner (Fulé *et al.* 2011); however, current Mexican fire regimes are changing, with some places decreasing in frequency due to fire exclusion policies (Fulé and Covington 1996), others increasing due to overuse (fragmentation and logging of wet forests). A recent nationwide investigation has defined 11 potential fire regimes in Mexico (Jardel *et al.* 2014) including: frequent surface fires of low severity (in grasslands and woodlands); low frequency canopy fires of high severity (in shrublands and some pine forests); low frequency surface fires (in humid forests) and ecosystems where fires are absent or very rare (rainforests). It is worth recalling that Mexico is a centre of diversification of pines (*Pinus spp*) and oaks (*Quercus spp*), two species groups strongly related to fire (Cavender-Bares *et al.* 2004; Romero *et al.* 2009; He *et al.* 2012; Pausas 2015*a*). Mexico harbors ~50 species of pines and together these incorporate all the fire strategies and traits observed in this genus (Pausas 2015*a*). There are many fire tolerant pines with thick bark, self-pruning abilities and in some cases with basal or juvenile resprouting capabilities (e.g. *P. motezumae*, *P. oocarpa*); there are also fire embracers (postfire seeders) with thin bark and serotinous cones (e.g. *P. patula*), and fire avoiders that lack these traits (e.g. *P. cembroides*) (Rodríguez-Trejo and Fulé 2003). The country also harbors some 160 oak species, ranging from strongly resprouting shrubby species (e.g. *Q. repanda*, *Q. frutex*) to tree oaks with relatively thick bark that live in surface fire ecosystems (Rodríguez-Trejo and Myers 2010), including both evergreen and drought-deciduous species with a large range of leaf morphologies. It is surprising to see some oaks with very large, and very thick leathery leaves that are deciduous (e.g. *Q. magnoliifolia*), certainly an outlier in the leaf economics spectrum (Wright *et al.* 2004).

At the community scale, we can also find various fire-driven vegetation states (sensu Pausas 2015*b*) in Mexico. For instance, some pine forests that are subject to frequent surface fires alternate with broad-leaved forests in the same environment (e.g. *P. douglasiana* forests; Jardel *et al.* 2014). In dry years, understory fires may spread into the broad-leaved forests and kill many of the trees, thus providing the right conditions for light-demanding fire-tolerant pines with flammable litter to enter the community. However, long periods without fire provide conditions for the colonisation of shade-tolerant broad-leaved trees. Similarly, fire exclusion generates pine woodlands with dense understories of broad-leaved trees that may eventually replace the pines in the absence of fire. Therefore, alternative vegetation-types are maintained by different fire regimes thanks to the differing traits of the species: fire tolerant pines are shade-intolerant, have thick bark and self-pruning ability, and generate a flammable litter; broad-leaved trees are shade-tolerant and fire-sensitive with thin bark.

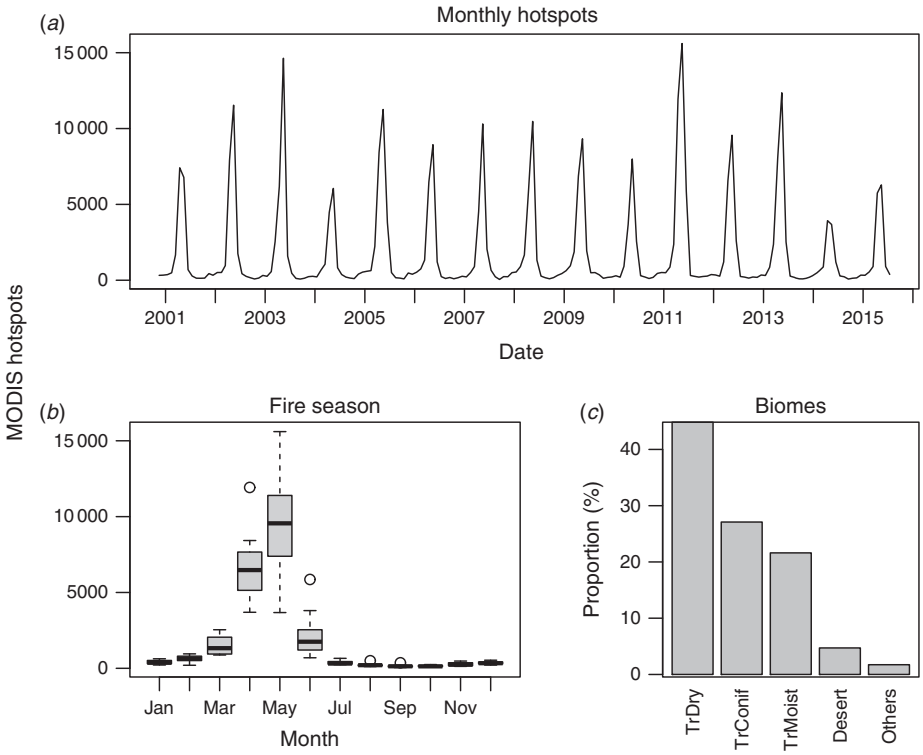

Fig. 1. Recent fire activity in Mexico (2001–2015) estimated from the monthly number of active fires recorded by the Terra satellite (MODIS hotspots). (*a*) Temporal variability (*x*-axis ticks indicate the beginning of the year). (*b*) Fire seasonality; the flammable season is concentrated into four months (March–June), with a peak in April–May (the end of the dry season). (*c*) Proportion of active fires in each biome (TrDry: tropical dry broadleaf forests; TrConif: tropical coniferous forests; TrMost: tropical moist broadleaf forests; Desert: deserts and xeric shrublands; Others). The MODIS fire data was downloaded from the University of Maryland (MCD14ML, http://modis-fire.umd.edu, accessed 10 November 2015), intersected with a country map and the biome map produced by the World Wildlife Fund (Pausas and Ribeiro 2013), and aggregated at the monthly scale.

Animals are by no means excluded from flammable ecosystems, as many animal species use the open habitat generated by fires. The iconic Mexican example are the migratory hummingbirds (Fam. Trochilidae), as they require open habitats with post-fire flowers for feeding (Contreras-Martínez and Santana 1995). However, there is a large diversity of animals that use these post-fire conditions.

All these extraordinary fire interactions in Mexican ecosystems, and much more, can now be explored in a new book entitled *Incendios de vegetación* (Vegetation Fires) by Rodríguez-Trejo (2015). This book written in Spanish (with summaries of all chapters in English at the end) is a comprehensive fire science text of 1700 pages published in 2 volumes; it is an extensive compilation of information and knowledge on this topic for Mexico, including 92 pages of relevant English and Spanish-language literature and plenty of pictures and tables. The first volume (18 chapters) starts with a general introduction to natural disturbances, and follows with a description of the fire regime and fire responses of each of the main vegetation types in Mexico: pine woodlands; oak woodlands; fir forests; gallery forests; grasslands; shrublands; rainforests; cloud forests; savannas; mangroves; swamps; palm forests and others. Each chapter has a similar structure, and includes the natural distribution of a vegetation type, its ecological and socioeconomic importance, fire regimes, fire response of species and populations, community and ecosystem processes related to fire and some management implications. This fixed structure of each chapter helps the reader find the relevant information for each ecosystem, although this approach can also be repetitive as some vegetation types share species and fire characteristics. The second volume (11 chapters) starts with the principles of combustion and flammability and is followed by chapters describing fire behaviour, fire prevention and suppression techniques and health risks for firefighters. These topics are explained in detail with some practical examples. The final 5 chapters are dedicated to a detailed fire history of the region; it starts with the origins of fire, concomitant with the origins of the land vegetation (Pausas and Keeley 2009), followed by the use of fire in prehistory, during the Mesoamerican cultures, and finally, describes the most recent fire history. In these chapters we learn not only about the use of fire in the landscape, but also how different cultures have used fire in art and spiritual ceremonies. In this context, the book presents abundant photos of pieces of art (e.g. paintings, pottery) showing evidence of the cultural role of fire (e.g. Xiuhtecuhtli, the fire-god in Mesoamerican culture). The book ends with a useful glossary.

If something is missing in this book it is perhaps an evolutionary view of fire; although Spanish readers can access this information in Pausas (2012). The text often uses the term 'adaptation' in a somewhat loose way. Strictly speaking, species currently growing under frequent fires cannot directly be considered adapted to fire. For example, plants that can resprout as an adaptive response to some fire-independent disturbances (e.g. hurricanes and herbivory) may also persist under low intensity fires. Therefore, in some cases, the pressure that shaped resprouting may not be fire and thus, resprouting could have an adaptive value under recurrent fires but may not be a true adaptation to fire (Keeley *et al.* 2011). This is why resprouting from rhizomes, roots or bulbs may not necessarily be fire adaptations, in contrast with resprouting from lignotubers or epicormic buds that are more related to fire (Keeley *et al.* 2011; Paula *et al.* 2016). Similarly, having high dispersal ability may enable the quick colonisation of burned areas but may not be a direct adaptation to fire. However, disentangling the role of fire from other disturbances in shaping plant traits is not an easy task as different disturbances may contribute to the evolution of traits (Keeley *et al.* 2011). In any case, clear adaptations to fire are evident in many Mexican ecosystems, especially in the pines as outlined above and in the species with fire-stimulated germination (Zuloaga-Aguilar *et al.* 2010, 2011). Further research on the evolutionary role of fire is needed in Mexico as this region is ideal for such studies. Another important topic that is not covered in detail in the book is the relationship between fire and climate and how climate change modifies fire regimes.

Overall this book is a must for anyone interested in fire ecology, fire management, and fire history in tropical America. It provides the basis for sustainable vegetation management in this region and advocates for the use of fire as a management tool. It may also be helpful for other Spanish-speaking researchers as it includes the general principles of fire ecology and management. The main message is that biodiversity of Mexico and its management cannot be understood without considering fire.

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