Planned burning is undertaken in Albacete, east-central Spain.

ECOLOGY

# Using fire to promote biodiversity

Biodiversity can benefit from fires tailored to suit particular ecosystems and species

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Fire profoundly influences people, climate, and ecosystems (*1*). The impacts of this interaction are likely to grow, with climate models forecasting widespread increases in fire frequency and intensity because of rising global temperatures (*2*). However, the relationship between fire and biodiversity is complex (*3*, *4*). Many plants and animals require fire for their survival, yet even in fire-prone ecosystems, some species and communities are highly sensitive to fire. Recent studies (*2, 3*, *5*, *6*) are helping to define fire regimes that support the conservation of species with different requirements in a rapidly changing world.

About 25 years ago, Martin and Sapsis argued that diverse fire regimes (pyrodiversity) promote biodiversity in environments where fire is a key disturbance (*7*). According to this hypothesis, higher spatial and temporal variation in fires produces a greater variety of ecological niches and thereby supports the coexistence of more species. Tingley *et al*. (*3*) recently tested this idea in a large-scale study of how variation in fire history shapes bird diversity in conifer forests in California, USA. They collected more than 38,000 observations of birds from 1,100 survey points, sampling a total of 97 fires. Some species in this region, such as the black-backed woodpecker, depend on habitat created by severe burns (*8*).

The authors show that different burn severities created unique habitats at local and regional scales, including areas with low and high cover of trees. Bird diversity was higher in places that had experienced fires with greater variation in burn severity; this effect increased in the decade after fire (*3*). The results provide strong evidence that conifer forests with high variation in fire severity are critical for sustaining biodiversity. The likelihood of such fires has been reduced in the past century by fire suppression.

In another recent study, Ponisio *et al*. (*5*) collected more than 7,000 pollinator specimens, and observed pollinator visitation on 71 flowering plant species, at sites that differed in past fire intervals and burn severities in conifer forests of Yosemite National Park, California. Diversity of both pollinators and plants was higher in areas with higher variation in fire interval and severity. This study provides further evidence that variation in fire regimes supports the coexistence of more species in conifer forest. It also shows that pyrodiversity can promote biodiversity through interactions across trophic levels (*5*).

However, increasing variation in fire regimes does not necessarily increase biodiversity. For example, work we have done with colleagues from Australia found that in semiarid eucalypt woodlands, the diversity of birds was not correlated with increasing spatial variation in pyrodiversity. This was because long-unburnt vegetation provided disproportionately important habitat (*9*). Similarly, Berry *et al*. (*6*) found that large patches of long-unburnt eucalypt woodland have particularly high levels of bird diversity because they contain critical food and shelter resources, such as large trees, that support many species. Together, these recent studies (*3, 5, 6*) show that it is important to consider how fire influences both the diversity and area of suitable habitat across a suite of species (see the figure).

Research on fire-driven variation is proving valuable in developing new, theory-based approaches for determining fire patterns that support biodiversity (*10*). For example, consideration of plant life-history traits, including the time to reproductive maturity and senescence, can help to estimate lower and upper limits of intervals between fires that best support different species (*11*). Identifying appropriate limits for other characteristics of fires, such as severity and patch size, is in its infancy. Through studies such as those discussed above (*3*, *5*, *6*), we can begin to de-

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fine desirable ranges of variation for multiple characteristics of fires (*12*), tailored to support particular ecosystems and species (see the figure).

Fire and biodiversity cannot be understood in isolation from other drivers of environmental change. Enright *et al.* (*2*) recently showed that a hotter, drier climate will reduce the range of fire intervals that allows plants to persist. This "interval squeeze," which is caused by changing levels of moisture under climate change that influence plant growth and reproduction, has the potential to alter ecosystem structure. Plant species that depend on canopy-stored seeds for population recovery after fire are particularly vulnerable to interval squeeze. This includes species from iconic families of shrubs, such as Hooker's banksia (Proteaceae), found in biodiversity hot spots in Australia and South Africa (*2*).

Fire-prone ecosystems are changing in other ways. Urbanization in southern Australia and western USA, regrowth of forests on abandoned land in Europe's northern Mediterranean, deforestation in tropical South America and Asia, and invasive plants in South Africa are all radically modifying fire regimes and biodiversity (*1*, *4*, *11*, *13*). Developments in fire ecology (*2*, *3*, *5*, *6*) provide new avenues to couple models of animal and plant responses to fire with landscape simulations and scenario analyses to predict biodiversity change in these complex landscapes (*9*). Rapid progress in the development of models and decision tools—including through global efforts such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)—is also helping to make better choices about when and where to conduct planned burning and fire suppression (see the photo), while considering uncertainties such as the occurrence of wildfires and droughts (*9*).

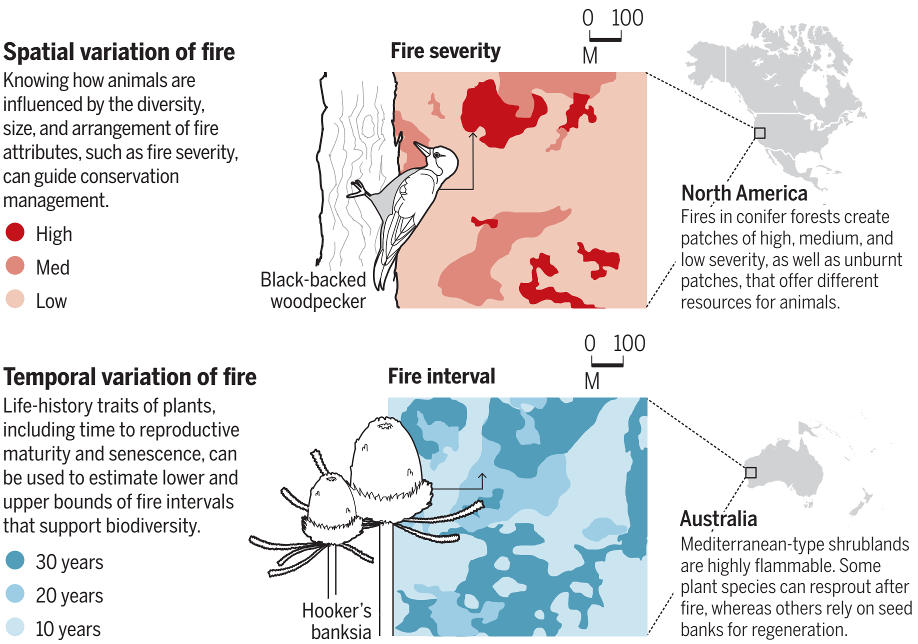
Land managers and policy-makers are increasingly putting these novel tools and approaches, such as species distribution models, fire behavior simulations, and numerical optimization, to use (*1*, *9*). In doing so, one practical challenge is the integration of growing scientific knowledge with valuable place-based knowledge of fire held by people. For example, research in the deserts of Western Australia is providing insights into how Aboriginal hunting fires support the coexistence of multiple species by generating variation in the size of, and distance between, unburnt patches (*13*). Partnerships between scientists and indigenous landowners in savanna landscapes of Arnhem Land, northern Australia, are showing how use of fire that incorporates traditional and contemporary practices can achieve multiple socioecological objectives. By implementing traditional patchy burns using incendiaries dropped from airplanes or helicopters, such partnerships are enhancing biodiversity and reducing greenhouse-gas emissions over large areas (*14*).

Another practical management challenge lies in uncertainty about biodiversity responses to fire. Van Wilgen *et al.*'s study of adaptive fire management of highly flammable savannas of Kruger National Park, South Africa, points to a way forward in applying research (*15*). Here, fire management in landscapes supporting large herbivores such as elephants, sable antelope, and zebra has been designed to achieve ecological objectives defined by thresholds in the area and intensity of fires. This adaptive approach is underpinned by experimental manipulation of alternative fire regimes and a framework involving ongoing research, monitoring, and evaluation. One measure of success highlighted by van Wilgen *et al.* is that fire management policy in Kruger National Park changed when research showed that managers could influence the spatial configuration and seasonal distribution of fires, but not the overall amount of fire.

There is a need to further develop fire management approaches that, while supported by ecological theory, are better tailored to local conditions. Critical limits or thresholds in patterns of fires that support multiple species, including both plants and animals, remain to be identified. Large-scale data on fire and biodiversity are becoming increasingly available, creating opportunities for cross-continental comparisons and better integration of empirical data with new developments in ecological modeling. Interdisciplinary approaches involving ecologists, climate and fire modelers, scenario planners, and social scientists will help to ensure that we better understand and use fire to promote biodiversity. ■

## Connecting pyrodiversity to biodiversity

Biodiversity can benefit from variation in fire regimes tailored to suit the needs of particular ecosystems and species.




GRAPHIC: G. GRULLÓN/*SCIENCE*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