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Towards a sounder fire ecology

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Abstract
This forum brings together fire ecologists from outside the current wildfire controversy in the US to give their views on three central topics related to ecosystems in which wildfires are an important process. First, how do fire behavior and ecological effects vary between ecosystems? Second, why does this variation require an understanding that goes beyond simple correlations between various fire and ecosystem variables to more careful causal models? Third, how can human values and goals be reconciled with fire disturbance processes in an ecologically sound manner?

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Towards a sounder fire ecology

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Wildfires have been much in the news in the last few summers. Often, these fires are reported in adrenalin-charged terms like "firestorms" or "catastrophes", yet ecologists have known for almost half a century that fires and other natural disturbance processes are normal components of ecosystems. However, the probabilistic nature of these disturbances has left the public with the impression that they are unexpected. Perhaps more important, the public seems to understand little about how fires work and how they affect specific ecological processes.

A good example of this is the confusion over the issue of fuel accumulation. It arises from the clash between a simple, compelling idea – fires require fuel – and the more complicated reality of how wildfires actually operate. The argument goes something like this. Decades of fire prevention have led to the accumulation of fuel, which has made the forest abnormally flammable. This, in turn, has caused the increase in areas burned in recent years. Thus, the proposed solution is to reduce fuels through cutting and/or frequent low intensity management burns.

How could a better understanding of fire behavior illuminate this argument? First, years in which large areas are burned do not occur at regular intervals, because of the exceedingly important role played by large-scale weather patterns. Major fire years are usually associated with large-scale atmospheric patterns such as the El Niño Southern Oscillation, the Pacific North America Pattern, or the North Atlantic Oscillation, which cause persistent high pressure systems that lead to extreme fuel drying. The past decades may have seen an increase in the frequency and intensity of these events.

Second, whether an ecosystem has a regime of surface fire, crown fire, or a combination of both depends on the surface fire heat output, the height of the tree crowns, the amount of fuel in the crown space, and the rate of spread of the flaming front (Van Wagner 1977; Albini 1986). Ecosystems such as the North American ponderosa pine forests once had frequent surface fires that maintained their open canopy. Grazing, logging, and the prevention of surface fires over the past century allowed a closed canopied forest to develop, changing the fire regime from frequent surface fires to infrequent crown fires.

To explain this change as simply a fuel accumulation issue is confusing and misleading. For example, a similar change in the oak savannas of the US Midwest at the end of the 19th century did not result in a shift to a crown fire regime. Furthermore, because of the confusion over the role of weather and the poor understanding of fire behavior, the fuel accumulation argument has been extended to most ecosystems, and in particular has been used to explain years in which large areas burned in closed-canopied ecosystems such as subalpine and boreal forest, as well as chaparral shrublands.

In recent years, the fuel accumulation issue has become politicized, with environmentalists being blamed for preventing foresters from doing their job and thus allowing fuel to accumulate. A similar controversy erupted during and after the Yellowstone blazes of 1988. Here again, fuel accumulation supposedly played an important role in these subalpine forest fires. At the heart of this debate, often hidden by the smoke of politics, are several fundamentally important issues on which ecological science can offer some help. These issues are more universal than the current controversy in the western US.

This forum brings together fire ecologists from outside the current wildfire controversy in the US to give their views on three central topics related to ecosystems in which wildfires are an important process. First, how do fire behavior and ecological effects vary between ecosystems? Second, why does this variation require an understanding that goes beyond simple correlations between various fire and ecosystem variables to more careful causal models? Third, how can human values and goals be reconciled with fire disturbance processes in an ecologically sound manner?

We will need to answer these three questions if we are to make informed decisions, whether it is to live with fire as part of normal ecosystem processes while safeguarding human life and property, or to undertake large-scale ecosystem manipulations to try and produce specific fire regimes. By expanding the discussion to other ecological systems and to a more biophysical fire process/ecological response approach, we hope to dissipate much of the confusion surrounding the current wildfire controversy.

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Three main guidelines have been used to assist land managers with fire policy in Australia: let nature take its course; do what the Aboriginal people once did; and set goals appropriate to the time and place and use fires, as appropriate, to achieve them (Gill 1977). The first of these, the *laissez-faire* approach, has been considered by some to be geared towards an "ancestral condition" so that, if everything is left alone, nature will look after itself. However, it ignores the long occupation of much of the continent by Aboriginal people, and assumes that current patterns of ignition and suppression, fragmentation, fuel structures, and the history of white settlement generally have had no lasting effect.

The second guideline presupposes that Aboriginal culture was static, that we know which fire regimes were employed and at what scales, and that we can reproduce them. The third guideline assumes that we can define our goals in such a way that they are compatible within a region where management goals are mixed, that these goals are internally consistent or that inconsistencies can be resolved, and that fire regimes can be harnessed sufficiently to achieve them. In many cases, we have no option but to accept this last guideline because of the need to protect lives and property, because of the state of our knowledge, and because of the changes wrought in ecosystems since white settlement.

It is obvious by inspection and experience that vegetation types and fuel arrays vary widely and occur in a wide variety of climatic and topographic situations (see Bradstock *et al.* 2002 for Australia). Given the wide variation in inflammability between these fuels, it is apparent that fire behavior will vary between ecosystems.

By their very nature, models are never perfect, since they deliberately invoke the fewest possible variables to explain as much variation as possible. Fire-prediction models provide an estimate of an output, such as rate of spread, about which there is variation, usually unstated (Gill 2001). Even with a limited number of variables, some understanding of fire behavior can be reached, whatever sort of vegetation is affected.

The fire behavior models used in Australia over the past 40 years have been empirical. As fire-behavior guides, these models correlate rates of spread (or other variables) with variables such as grassland curing (percent of dead material), air temperature and humidity, amount of last rainfall, wind speed, and drought condition (as "soil dryness index", a measure of soil-moisture deficit). The curing variable is a partial surrogate for the basic variable of moisture content. For the common fire-behavior guide used in the eucalypt forests of southern Australia (McArthur 1967), the quantitative variable "soil dryness" or "drought index" seems puzzling because it has no obvious direct mechanistic connection with a fire behavior variable. Nonetheless, it seems to be useful.

Heat released from a fire affects organisms in its path. The processes of heat transfer remain the same, regardless of the ecosystem. The effects then depend on the reactions of the organisms to the heat they receive. A useful fire-behavior variable that couples fire to its effects is "intensity" (Byram 1959). This can be linked to scorch height (height of leaf death), for example (see Burrows 1994 for Australian correlations). When scorch height equals the height of the tree or shrub, death results in populations of selected species (obligate seeders) because of the death of all their buds (eg Gill 1995). Not all species are like this. In all ecosystems there are various proportions of species with a range of behaviors that allow them to live in the same fire-prone environment.

In longer-term studies we need to turn to fire regimes to predict ecological effects. Using probability models that are firmly based on a sound knowledge of processes, our ability to predict or explain outcomes will improve. In Australia, Gill *et al.* (2002) suggested that, for biodiversity studies, we need to "achieve an integrated body of concepts that link fire regimes, biodiversity, and management systems in ways that are applicable to all Australian ecosystems. The underlying links may be substantially similar, although they may differ quantitatively". Because of uncertainties in the models and our knowledge, astute managers will need to monitor the effects of their fire regimes in relation to set values and goals.

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For visitors arriving in Sweden from other boreal regions, their first observation may be that here in Sweden, at the western edge of the Eurasian taiga, forest fires are under control. Wildfires burn, on average, less than 1500 ha per year, equivalent to a fire cycle of 15 000 years. It might therefore come as a surprise to learn that until 150 years ago the fire cycle ranged from 30 to 80 years in most of the country (Zackrisson 1977; Niklasson and Granström 2000; Niklasson and Drakenberg 2001). In the late 1800s, as large-scale forest harvesting expanded, fire frequency dropped dramatically within a few decades. This was at a time of poor infrastructure and simple hand tools, which suggests that the fires were of generally low intensity.

The circumboreal biome may seem uniform, but the virtual elimination of fire that occurred in Sweden towards the end of the 1800s evidently could not have taken place in Canada or eastern Siberia, and still cannot, given the high-intensity crown fires that are typical there (Stocks *et al.* 1996; Weir *et al.* 2000). What, then, is the key factor behind the apparent difference in fire behavior between different parts of the boreal region? There is no readily available answer yet to this fairly simple question, and it may serve to highlight our current ignorance. Many factors come into play; fire depends on the structure of the fuel and its display on the landscape, weather, and ignition sources. Fuel is not a prime candidate in this case. Surface fuels such as litter and moss are remarkably similar throughout the boreal zone. Canopy fuels can vary more, but typically conifers, often species within the same genera (eg *Picea* and *Pinus*) dominate. Weather is the strongest candidate, given the major effect of wind and fuel moisture on fire intensity, but the analysis is still lacking.

The Swedish fire scene today may seem peculiar from a global perspective. The general public tends to perceive fire as a positive natural force. No doubt this is partly due to the small area burned, but there has also been a lot of good publicity in the media. On the other hand, very few people have an intimate knowledge of forest fires. Consequently, there is fertile ground for myths to propagate, especially regarding the links between fire behavior and its effects.

The present interest in fire seems to have been inspired by discussions in the US in the 1970s, and a general notion that fire was once important naturally and should therefore be reinstated. This eventually translated into the increased usage of prescribed fire in forestry. Today, a voluntary forest certification agreement between all the major forest companies and conservation organizations states that 5% of the annually cut area must be treated with prescribed burning. Usually, 5–15% of the timber is left standing in the harvested areas and these are included in the burning. The rationale for this is to substitute wildfire with prescribed fire in order to maintain the biodiversity that is linked to fire.

Will it actually work? Here we must look beyond the broad connection that can be made between fire regime and biodiversity. Is fire needed to maintain biodiversity in the boreal forest at all? If so, what are the exact mechanisms involved? The answer will be very different, depending on which organisms are of interest (Granström 2001).

Another avenue for fire management is prescribed burning in forest reserve areas. Until now, this has been very marginal, probably because of a reluctance to burn in the small areas of old growth forest we have left. Right now, a large number of new reserves are being established and there is considerable interest in introducing fire as a means of restoring them to a more "natural" state. Again, this has been loosely inspired by the discussions in the US. Management is decided at a local administrative level (there are 24 such units in the country) and usually with little support from research. It is valid, therefore, to ask if science really does influence management, except at the broadest level. Here in Sweden, the lack of both a proper research base and personnel with a solid fire background are a problem.

Whether the present fire policy is actually the best in terms of conservation or not, it has stimulated some long-overdue fire research. In contrast to Canada, the US, Russia, and Australia, we have never had a strong tradition of research on fire behavior, simply because wildfire has not been a serious threat, since forestry-related research was first established about a century ago.

The fact that the fire regime in this part of the world is now almost totally under human control – and is therefore our own responsibility – should inspire both researchers and managers. For real progress, however, we need a more mechanistic understanding of fire behavior and fire effects. That is still far off in the future, but I cannot resist paraphrasing Dobzhansky`s (1973) famous statement about evolution: "Nothing in the boreal forest makes sense except in the light of fire!"

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In the countries around the Mediterranean Sea, wildfires destroy about 300 000 ha of forests and shrublands annually (Chandler *et al.* 1983). Today, lightning fires play only a minor role, accounting for about 2% of the annual area burned; the other 98% is of human origin. One of the characteristic features of plant communities on the periphery of the Mediterranean Basin is their floristic and ecological heterogeneity. More than 90 tree species share in the composition of the forests. This heterogeneity is linked to a number of factors, including the history, climate, physiognomy and soils of the area. Plant species exhibit widely differing behaviors toward fire, with many adaptations: they can resist fire through epicormic buds (protected by bark or cork) or can survive as belowground entities, such as bulbs, rhizomes, tubercles, and seeds.

Ecosystems in the region have a tendency to organize at successive altitudinal levels, from the seashore to mountain summits. However, due to climatic compensating factors and substantial human impacts, plant communities are highly intermingled (Ne'eman and Trabaud 2000; Trabaud 2000). Coniferous forests (largely *Pinus* sp) occupy very large areas of the Mediterranean periphery, while Mediterranean firs (*Abies* sp) cover a smaller proportion. Sclerophyll forests, consisting mainly of a few species of oaks (*Quercus* sp), cover huge areas, while deciduous forests are composed of numerous different species. As a result of the long history of human occupation, half of the landscape is covered by shrublands (called variously *maquis*, *garrigue*, *matorral*, *macchia*, and *phrygana*), in which hundreds of species coexist.

In the Mediterranean region, ecosystems tend to regenerate to a structure and floristic composition similar to pre-fire conditions. After fires, plants appear rapidly and cover the ground surface. Nearly all studies (Ne'eman and Trabaud 2000; Trabaud and Prodon 2002) have reached the same conclusions: (1) the abundance of herbaceous species (mostly annuals) is quite remarkable during the first years in burned areas; (2) the majority of species that gain dominance during the reestablishment of mature vegetation are present in the first few years after fire; (3) the reestablishment of previous communities occurs rapidly; and (4) as burned communities age, returning to a state similar to that of unburned systems, structure becomes more and more complex, and involves numerous layers. The herbaceous layers that predominate during the early stages decrease and are replaced by shrub and tree layers.

Most plants that appear after fires come from survival organs such as rhizomes, lignotubers, bulbs, and seeds, which were present in the soil before the fire, or were dispersed immediately afterwards from nearby plants or plants that survived in unburned patches. No plants alien to the previous stands are able to invade and persist. All the pre-fire species are present almost immediately after fire, even if the relative abundance or frequency of individual species changes later on. There is no succession or floristic relay of different communities; the plants that persist are those that existed previously and those that appeared immediately after fire.

Biotic communities of the Mediterranean Basin exhibit a high tolerance to fire. How can this be characterized? Fire, repeated over millennia, eliminates less resistant species, thus reducing potential competition. Only species and populations able to resist and adapt to repeated disturbances persist. Thus, the ecological systems of the Mediterranean Basin are "dynamically robust", characterized by a high resilience associated with a strong inertia and a noteworthy persistence.

Do fire cycles exist? Knowledge of fire frequencies is extremely important in understanding the relative stability of these ecosystems. When fires occur too frequently, notable changes may occur in plant or animal populations, and some species may disappear. However, the repetition of infrequent fires leads to species and community permanence. In fact, the present ecological systems of the Mediterranean area are the result of influences over millennia, during which species acquired mechanisms to overcome fire effects as well as to resist other environmental constraints such as drought and cold. Fire, human activities, and climate have all favored an ecological and genetic differentiation, resulting in the present makeup of the fauna, flora, and vegetation. Because of these past vicissitudes, fire today is not a factor of change for Mediterranean ecological systems. Each species uses its own characteristic survival traits, best adapted to its needs, which allow it to survive disturbances and to perpetuate itself, thereby maintaining the communities in which it lives.

Management strategies that ignore the fundamental instability of ecosystems are completely unsound and ultimately lead to surprises. As fire plays a role in practically all Mediterranean ecosystems, it must be considered an integral part of any management planning. However, we must recognize the effects of fire on renewable resources, and select the values we wish to protect. In the global process of ecosystem dynamics, each participating species has different needs. Some plants grow only in the shade of forest stands, while others thrive only on rocky sites or full-lit swards. This is also true for animals.

Fire is not always negative. To protect a forest from fire, we need to use all the most modern technologies. To preserve a *garrigue*, however, we can let the fire burn, because the shrubland will rapidly return to its previous state, and will eventually regain all the original faunal and floral components.

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At the root of the debate over whether or not North America's recent, costly wildfires are normal or not is the problem of "two solitudes in forest fire research" (Van Wagner 1971). One isolated group involves most ecologists and foresters who, unsurprisingly, focus on the ecological and management aspects of wildfires (tree mortality, regeneration, fire spread, etc), rather than on the physical processes involved in wildfires, such as ignition, fire–atmospheric coupling, propagation and extinction of smoldering and flaming combustion, and large-scale climatic processes. This group's research approach has largely been descriptive–correlative and based on case studies, which neither reveals the causal variables nor leads to an understanding of their relationships with each other and the ecological effects of interest.

The other "solitude" involves primarily physical scientists who study processes of combustion and heat transfer, including combustion engineers, mechanical engineers, atmospheric physicists, and biophysicists (Saito *et al*. 1989; Baines 1990; Ohlemiller 1990). While the focus of this group's research is often on the burning of materials other than natural vegetation (eg oil fires, house fires, and smoldering in tobacco, furniture, and insulation), the understanding they have developed of the physical processes of fire have been found to be applicable to understanding the behavior and effects of wildfires (Van Wagner 1972, 1977; Albini 1981, 1985; Weber 2001).

What is needed now is to bring these two groups together. This is not a new argument (Van Wagner 1971; Johnson 1992). It is apparent that much of the current controversy and debate is due to a lack of precise understanding of fires and their effects by most fire ecologists. The descriptive–correlative approach prevalent in fire ecological studies can lead to imprecise thinking about how to study fire behavior and fire effects. One example of this lack of precision is the failure to distinguish between the concepts of temperature and heat; this has led to the use of instruments and measures (eg heat-sensitive paints or painted cans filled with water) with no clear indication of what property or behavior of fire is actually being measured. Indexes are often produced and used to describe variation in fire behavior, or are correlated with some ecological effects with no basis in, or involvement of, any physical or biological processes; these end up being not much better than saying that the wildfire was hot or the effect was severe.

These two solitudes stem largely from the fact that most of us tend not to look at the literature outside our own field, nor ask if the problem we are studying has been addressed in some other field of study. Thus, foresters and ecologists have generally used databases such as Biological Abstracts or Forestry Abstracts, rather than Compendex (Computerized Engineering Index). Furthermore, even if such literature is found in a topic search using a more general database, such as Web of Science, a lack of background in other disciplines (mechanical engineering, combustion science, or atmospheric physics, for instance) may make it difficult to appreciate the relevance and usefulness of the study, and to think about how to use the information to address a fire ecology problem.

What we need, then, is a concerted effort among universities, granting agencies, and government departments to train and encourage people to bridge this gap and to promote such interdisciplinary research. Specifically, what we advocate here is the process–response approach to fire ecology (Johnson 1985; Johnson and Miyanishi 2001), which couples physical fire processes to the ecological responses of plants, plant parts (eg cones, seeds, bark, meristems), or other organic ecosystem components.

What can the various institutions do to promote this research approach? Universities might offer undergraduate courses and workshops for graduate students and professionals, taught by interdisciplinary teams of physical and biological scientists. Granting agencies should try to recognize the value of such interdisciplinary research proposals, even though they often do not fit strictly within the remit of a particular grant committee or panel. (The National Science Foundation has already taken this step recently, in forming the Biogeosciences Directorate.) Government agencies that both conduct research and fund external research might also do their part to encourage more interaction between physical and biological scientists.

Once we develop a better understanding of the fire processes, ecological responses, and their coupling, we will begin to understand how fire behaviors and their ecological effects are similar and how they differ between different types of plants and ecosystems, such as closed canopy chaparral, conifer forests, savannas, and grasslands. Ideally this will lead us away from the extremes of the "one-size-fits-all" and the "each-ecosystem-is-unique" approaches to fire management.

Furthermore, a better understanding of the process–response connections in wildfires should make it clear that, while science can only inform us about potential effects of various management decisions, it cannot inform us about "how things should be". For example, the use of words such as "destructive" and "catastrophic" to describe crown fires in closed-canopy ponderosa pine ecosystems seems to imply that these closed-canopy conditions are somehow "wrong". Most fire-prone ecosystems have experienced a range of fire regimes in the past, and there is abundant evidence in the literature that in most cases these fire regimes have changed fairly frequently. Thus, the choice of regime for a particular ecosystem must be based on what type of ecosystem we want or value – for example, open versus closed canopy – and cannot be based on some notion of what is "natural" or "right".

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