

Problems, paradoxes, paradigms: triangulating fire research*

Stephen J. Pyne

School of Life Sciences, Arizona State University, PO Box 874701, Tempe, AZ 85287-4701, USA.

Email: stephen.pyne@asu.edu

Abstract. Wildland fire research has historically orbited around a physical paradigm of fire. This strategy has yielded remarkable results, yet increasingly it cannot speak to the core issues that concern fire management. Two additional paradigms are needed. One would build on fire's origins in the living world. The other would evolve out of fire's significance to humanity, and humanity's unblinking importance to fire's presence on Earth. Note that each paradigm is coherent in itself, that each is capable of absorbing the others, and that each is insufficient on its own. It is unlikely that a master synthesis of these conceptions will emerge, and is not necessary. The need is to sustain research that addresses how fire really exists, not how select sciences can handle it. This essay sketches what the resulting fire-research triangle might look like.

Additional keywords: anthropogenic fire, biology of fire, culture of fire, fire modelling.

The proper study of fire: what should fire-research study, and how?

Echoing Alexander Pope, we might argue simply that the proper study of fire is fire. But fire can assume many definitions, which seems only suitable for so malleable a phenomenon and one whose deification repeatedly turns to shape-shifting tricksters like Agni and Loki. Instead, almost every discipline has its own definition of fire, each framed by conditions outside fire itself, which seems to possess, by itself, no intrinsic intellectual identity (the only fire department at a university is one that sends engines when an alarm sounds). So what then are fire's real fundamentals? On what characteristics should we undertake its control and use? What sort of inquiry – what science, what scholarship, what vernacular lore – should guide our understanding?

Such concerns seemed like pedantic quibbles when the founding task of fire research was to support fire control. Fire was simply there, smouldering and flaring across landscapes, and research was asked to predict where it would go, how fast, and how fiercely, and to devise means to halt its spread. As other questions emerged, particularly economic, and later ecological, they were grafted onto this rootstock, a conception of fire that was implacably embedded in the physical sciences. Fire affected biotas and societies rather as floods or windstorms did. Yet, increasingly, this tradition, while flourishing, can answer fewer of the critical questions that trouble fire's management.

When the deep driver of planetary fire is the burning of fossil biomass, when free-burning fire is disappearing from the developed world except on reserved lands, when public concerns over nature protection hinge on biological indices like ecological integrity, biodiversity, and sustainability, when the prime threats from wildfire are to houses along a fractal exurban fringe, when the common element among every fire problem is

humanity – people as fire kindlers and fire suppressors, people as direct and indirect shapers of landscapes on a geological scale, people as judges of what is and is not a fire problem (or a solution), people as operators of industrial combustion on such a scale that they are unhinging even climate, that ultima Thule of fire's physical environment – then the contemporary design and emphasis of fire research might well appear to an unbiased outsider as eccentric, the residue of a cockeyed historic evolution. Like the drunk who keeps searching for his lost keys under the streetlight because 'that's where the light is,' fire research continues to elaborate a physical paradigm because that's where the funded science is. But the keys to understanding may lie elsewhere. The time has come to recharter our conception of what fire is, how we might study it, and how we ought to manage it.

Fire is what its circumstances make of it. But given the fire community's predilection for triangles, consider a research program that arises from three conceptual constructions of fire; each is internally consistent, each fully encompassing, each equally necessary. In their intellectual power they are coequal. The historical reality, however, is that one ring has ruled them all.

The physical paradigm

This, the founding paradigm, asserts that fire is a chemical reaction moulded by the physical characteristics of its environment. Those physical parameters shape the zone of combustion as it moves about the landscape; how that happens and with what consequences define the realm of fire research. These are fire's fundamentals.

From such processes flow all other fire effects, and from this model derive all other explanations for why and how fire exists

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on Earth. Fire ecology is the study of how fire, as a physical disturbance, interacts with the living world. Fire policy and fire sociology are the study of how, granted fire's physical properties, people should apply and withdraw fire and how they should protect themselves from its threats. Fire management consists of exploiting fire's physical behaviour – to check its spread with physical countermeasures and to kindle its benefits by arranging ignition and fuel. Fire science is the study of landscape as firesheds, its combustion chambers framed by weather and terrain. The future of fire research is to extrapolate this physical paradigm into more and more phenomena.

This conception does not arise inevitably and uniquely out of the subject. It expresses the bias of past funding, which reflects the desires of state-sponsored forestry to control free-burning fire on public lands. These agencies typically assumed exclusive sponsorship over fire scholarship. Without them it is possible there would have been almost no research done, but through them funding privileged some topics and disciplines over others. The issue, in brief, is one of intellectual politics and institutional monopoly. Fire never got properly situated in biology, the social sciences, or the humanities. Research flowed over a single floodplain, and the more it flowed, the deeper the dominant channel became. Even recent initiatives like the Joint Fire Science Program in the USA (welcome as it is), demand a scholarship based not only on natural science but on those branches of science capable of translating ecosystems into fuels and describing how fuel arrays influence fire's behaviour.

The problems with this approach are several. Partly they arise from the limitations of this perspective relative to the problem at hand, partly from way the physical paradigm is imagined, and partly from the tendency to demand that all other conceptions align with this paradigm in what becomes in fact (if not by intention) a hegemony. Laplace famously (if fatuously) pronounced that if he knew the position and velocity of every atom he could predict the future of the universe. As elaborated, the physical paradigm echoes this claim, that once it knows the position and flammability of every fuel particle, it can predict the outcome of every ignition, that all it needs to complete its public agenda are better models, denser instrumentation, and more powerful supercomputers. This is less a hardnosed philosophy of science than an archaic one, long abandoned in higher physics. Even if it could be done, controlling fire's behaviour is only a fraction of fire's management.

Still, this would not matter much – each discipline could search out its natural level – if the scene did not come with the implicit understanding that what doesn't fit these strictures doesn't exist, not as science. Other scholarship acquires power only to the extent that it flows from or aligns with these precepts and style. The issue, that is, pivots on the privileging of the physical paradigm over other conceptualisations. The American fire community appreciates the historic significance of the Tall Timbers Research Station as during the 1960s it offered an alternative forum, outside government funding agencies, for promulgating ideas about fire ecology and prescribed fire. In today's political lexicon it contributed to a more textured civil society. What the fire community needs now is an intellectual equivalent, for while it has become a truism that the sticking points in fire management involve ecological themes as refracted through cultural understanding and politics, the discourse must be cast

in the language of fuels and limited to questions of fire's control, which is to say, it must remain within the domain accessible to the physical paradigm.

Presently, the physical paradigm so suffuses fire research that it seems less an intellectual convention than an axiom. It is everywhere, and its accomplishments are genuine; undeniable, ubiquitous, and profound. It continues to produce intellectual excitement as well as practical prescriptions, of which recent studies on crown fires and eruptive fires especially stand out. Most of the fire community can probably imagine no other approach. Yet like Euclid's Fifth Postulate, the physical paradigm is neither inevitable nor logically necessary. Change its founding assumption, and other, wholly consistent conceptual geometries of fire are possible.

A biological paradigm

An alternative perspective might consider fire as biologically constructed, as a reaction created and sustained by biological processes. In this conception, the fundamental conditions of fire's behaviour are set by the living world: life is why fire exists, the living world moulds fire's expression, and physical parameters matter only insofar as they are refracted through a biota. Fire's environment is primarily organic. Fire's real fundamentals reside in the properties of its biotic setting.

The basis for such a proposition is simple: life creates oxygen, life creates combustibles, and life, through the agency of humanity, overwhelmingly creates the sparks of ignition. The chemistry of combustion is a *biochemistry*: fire takes apart what photosynthesis puts together. Within a cell, the process is called respiration; within the wide world, fire. The arrangement of combustibles is fashioned by evolution and ecology, which are themselves responsive to biological processes, not simply derivatives of a physical environment. While terrain and climate help shape particular patterns of fire, as they do for evolution and ecosystems generally, they express themselves through the resulting arrangement of organic matter, or bio-combustibles. Fire's integration occurs within the biosphere.

In this conception, fire's ecology is not simply the record of disturbance by mechanical forces acting on a biological medium but a propagation *through* a biotic medium. Wind, ice, debris flows, floods – all can occur without a particle of life present; fire cannot. It literally feeds upon biomass, more resembling an outbreak of bark beetles or SARS than a windstorm or a glacier. The expression that such-and-such a disease spread like wildfire could be restated to read that such-and-such a fire spread like a disease, a contagion of combustion. Life need not simply adapt to fire: it breeds, nurtures, and shapes fire. Fire becomes less a mechanical force that impinges on ecosystems so much as an organically informed process that manifests itself in such physical expressions as heat and light.

Ideas have consequences. Overall, fire ecology defers to the physical paradigm, which strikes the data of ecology much as it imagines fire striking an ecosystem. At issue is not whether fire is 'natural,' but in what way it is natural. Is it a physical process like wind and lightning that must, in its basics, be described by physical science? Or is it an organic process that cannot be abstracted from its biological setting? In some ways it is both, and neither. But if the first, then ecological solutions to fire problems

must ultimately lie with physical counter-measures; slashing, burning, quenching, rearranging blocks of hydrocarbons. A biologically based paradigm, by contrast, would propose biological controls.

These could range from genetically modified fuels to ecological engineering. Instead of fuel-laden firehedges, we could imagine fire habitats that fire shares with hosts of organisms, some of whom compete with it and all of whom shape its setting. Fire's reintroduction would resemble the reinstatement of a lost species. Fire's control would reside in its biotic context rather than along its flaming front. Here is a paradigm better suited to management on a landscape scale. Here is a conceptual language, as 'fuel' is not, to describe the significance of fire to biodiversity, ecological complexity and integrity, and sustainability. The physical paradigm was not propagated to answer such questions. Twisting it to do so is like asking a creature with flippers to handle objects as one with fingers could.

The breakdown, however, lies also with biologists, who have not seized upon fire for its value as a way to understand the peculiar properties of life on Earth. In recent years ecologists have broadened their niche – have, for example, begun to compare fire and herbivory; have argued for the evolutionary antiquity of fire as a selective agent; have strengthened the thesis that fire is somehow natural and necessary. But these do not add up to a biological paradigm of fire that would characterise fire as fundamentally a phenomenon of life – not simply something that life adapts to but that life makes possible, whose primary parameters are organic and whose explication and control should reside in its ecological setting.

Perhaps the biggest payoff is that a biological paradigm could incorporate humanity into the grand narrative of life on Earth. If a megafaunal mammal had emerged during the late Pleistocene and claimed a species monopoly to start and stop fires at will, and had blitzed across the planet, you can bet there would be considerable interest among biologists in what this creature means to planetary ecology. There would be subdisciplines, journals, and symposia devoted to the subject. Yet just this scenario happened. Apparently because the creature is *Homo sapiens* the topic stands outside biology, or if it is considered fit for analysis, the model is, once again, that of fire crashing into biology from the outside, much as people are presumed to force their fires, unnaturally, onto landscapes. It is possible to pick up the other end of that stick, however, and argue that in reality humans are completing the cycle of fire for the circle of life. Through people, life is increasing its control over combustion. The master narrative of fire is that it is becoming more rather than less biologically informed. The incorporation of people as biological agents should be one of the prime assets of a biological paradigm.

What may surprise casual critics is that this proposed reconceptualisation is potentially as coherent and consistent as the physical paradigm, and that it is fully capable of absorbing its rival. A biological paradigm can offer a parallel worldview in which fire becomes another expression of a biological Earth, along with the rise, extinction, and arrangement of species, and the cycling of carbon and nitrogen, and for which physical models become subroutines within the grand programming set by the living world. Under the prevailing regime, biological traits must be recast to fit physical parameters, not physical traits to

a biological conception. Yet just the reverse is entirely possible. A biological paradigm would centre fire within the living world, look to life to contain and exploit it, and make fire into something more than a sidebar and errant footnote in standard texts in ecology and life science.

A cultural paradigm

The cultural paradigm is both the most obvious and the least developed. It focuses on fire's species-monopolist, humanity, for whom fire's manipulation has always been a defining trait and whose present dominance relies on continued control over combustion. The story of fire on Earth is increasingly the story of what people do or don't do, directly or indirectly, with regard to fire and its setting. The cultural model would seek to record and explain this interaction. It assumes fire's fundamentals reside with us.

The difficulty with this approach is not that nothing has been studied, but that no conceptual organisation is in place to make sense of the data. A few studies exist, mostly from anthropologists, some examining aboriginal societies, most detailing slash-and-burn regimes, a couple focusing on the fire-based agriculture in Europe and America and changes in settlement rhythms. Only a handful attempt to tinker with a general model that links the diverse aspects of human fire practices or even to sketch a historical chronicle that embraces the full narrative from lightning bolts to SUVs (academic history has almost wholly ignored the topic, save for urban settings). There is no scholarship to analyse what institutions best serve fire management. There is no intellectual history of fire after the Enlightenment. There is almost no inquiry into fire as an organising device for the human occupation of the planet. And there is no truly political history of fire, which seems bizarre granted that contemporary fire agencies are overtly political institutions; for over a century the apparatus of wildland fire protection and research has occurred almost wholly under state sponsorship.

The reasons are the usual ones. There is no discipline of fire, so fire occupies nooks and crannies in other fields, and while there is funding for natural science, there is little for the social sciences and none for the humanities that deal with the institutions, social values, and cultural choices that guide humanity's fire behaviours. Such omissions become grotesque as one considers that the deep driver of fire on Earth today is the industrial revolution, which for fire history means replacing the burning of surface biomass with the burning of fossil biomass. For the developed world, the period of transformation – call it the pyric transition – is a time of abusive and damaging conflagrations. The demographics of industrialising fire closely resemble those of industrialising people, beginning with a veritable population explosion and ending with reproduction below replacement levels. Such eras became a powerful background to arguments in 19th-century Europe and North America for state-sponsored conservation and a flawed baseline from which to estimate background burning. Presently, however, there is no sense that this transformation is a part of fire research except as global warming might quicken the opportunities for megafires. A cultural paradigm, however, cannot avoid such matters: it is humanity's fire practices that are propelling global warming and humanity's

institutions that must cope with the maldistribution of burning that industrialisation has sparked.

Fire problems are socially constructed problems. They are problems because people define them as such, and nearly all the crises that fire inflames can be resolved by social means. After all, humanity has lived with, and exploited, fire for all our existence, and we have fashioned the fire regimes of the planet without the benefit of academic science. Trial and error, socially coded into prescriptions, have served to make fire available and keep it within acceptable bounds. People have been able to scorch fields, drive game, cook, fumigate, foster metallurgy and ceramics, counter wildfire, burn pastures, and otherwise put fire to the service of sword, plow, hoof, and hammer without a scrap of modern science. (On the contrary, Enlightenment science in the service of the modern state has systematically extirpated that entire encyclopedia of folk knowledge.) As the physical paradigm suggests physical means to control fire, and the biological paradigm biological controls, so a cultural paradigm would propose cultural controls. The available means are many, for whatever shapes people's understanding and behaviour can affect how they decide to apply and withhold fire. Whatever their ultimate origins, the levers of control will operate through institutions and ideas. They will reflect how we think of fire and define it as a concern.

This observation does not mean that people can exert total control over fire, only that we have the capacity to determine what control means and what kind and how much we will accept. All the data that the physical and biological paradigms can spew out will matter little if there is no means to apply it in ways that satisfy the human definition of the problem. The integration of these factors occurs within a social setting. Equally, we can resolve almost all the urgent problems of fire management through social means if we choose; by land management, by regulating behaviour, and even by deciding whether a fire free-ranging through wildlands is a cultural crisis or an ecological spectacle. Mantras that 'fire is natural' ignore the fact that in the industrial world free-burning fire thrives only on reserved public lands or on temporarily abandoned lands; neither condition is a state of nature; they result from social decisions. Even that ultimate natural referent, climate, is becoming unhinged by anthropogenic fire practices.

The cultural paradigm, that is, can absorb the other two. It can even explain why the physical paradigm dominates contemporary imagination, for science is a human enterprise conducted through institutions, and the question of which science gets supported (if any at all) is a social choice. Moreover, the cultural conception can offer its own justification for research, not for the techniques that science furnishes but as a cultural undertaking like art or opera that lifts fire's management beyond the realm of craft and guild. Understanding these dynamics matters as much as modelling the footprint of retardant drops or torching firs. American and Australian fire agencies, for example, have been hammered in recent decades not because they could not calculate fuel loads but because they could not speak to their sustaining societies. (Americans, in particular, might ponder that the most significant publication of recent decades, Norman Maclean's *Young Men and Fire*, came from a professor of Renaissance literature at the University of Chicago.) In this figuration, the physical and biological paradigms become sources of

particular information that serve the cultural paradigm, which alone addresses the core issue, how should humanity use its firepower and conduct itself as a fire creature?

Over and again, the sticking point on fire policies is uncertainty over what people want a landscape to be and what means they may have to pursue those ends. Before such matters, the physical and biological paradigms stand dumb. And while a cultural paradigm could not speak with the putative authority of laboratory science, it can at least speak with the voice of scholarship, and while not declaring what choice we should make, it can help us understand better the nature of the choices before us. Technology can enable, but not advise; science can advise, but not decide. For that we need other scholarship and a conception of fire that makes the process of deciding a point of integration, not an afterthought. We need a paradigm that unabashedly places people as fire creatures at its core.

Regime change: explaining megafires

Over the past 15 years, the world has witnessed an epidemic of megafires. Countries that thought they had banished open fire into their ancient past have seen it return; countries that assumed they had mastered wildland fire, holding it to a quantum minimum, have seen it break out of suppression with shocking fury; countries eager to develop new lands, either as plantations or parks, whether by clearing old forest or reclassifying former forests, have seen fire and smoke spread like a plague. And all have nervously pondered the growing evidence for an era of global warming, amid the scientific conviction that industrial combustion is an unwanted accelerant. How might the various paradigms interpret this outbreak?

The physical paradigm would point to climate change and its effect on fuels. Places that were normally wet became droughty, and hence available for burning on a grand scale, while land-clearing and land abandonment plumped vast terrains with combustibles. Fire simply followed those fuels and the tidal rhythms of climate. Analyse those arrays and you can understand and predict the nature of the impending conflagrations. Only in limited circumstances can people modify the master parameters through manipulating 'fuels'; mostly, they must meet force with force. Megafire thus appears like a tsunami, and calls for such remediation measures as physical barriers, early warning networks, and policies to compel people to adjust their lives to an unalterable reality. Too often, however, such analysis leads to the landscape equivalent of stuffing buildings with asbestos in the name of fire protection.

The biological paradigm would point to disrupted biotas – to broken forests, invasive pyrophytes, the collapse of internal checks-and-balances within ecosystems. The fires have behaved rather like an emergent disease, a pyric version of avian flu, with climate helping create favourable conditions (although catalysed and boosted by human practices), but with the propagating medium and vectors residing in the living world. What had been a seasonal nuisance has now mutated into a virulent and lethal plague. Rather than firefighting with pumps, aircraft, and retardant, a strategy of containment might look to epidemiological analogues and public-health strategies from vaccinations and sanitation to quarantines and select emergency care. The effects of such fires, even the worst fire plague, would vary enormously

among the populations affected. The metrics for determining the seriousness of an outbreak would reside in biological indices.

The cultural paradigm would note that, while drought and lightning have accounted for many of the burns, it is primarily people who are the agents of the outbreaks and who have determined what responses, if any, the fires warrant. They would note that the eruptions have resulted from interactions of natural conditions with changes in land use, institutions, policies, and perceptions, all of which have created opportunities for fire, and which suggest that megafires are analogous to a revolution or an evolving insurgency. Big fires have resulted from breakdowns in the apparatus for fire control that followed political upheaval in Russia and especially Mongolia. Big fires have swept half or more the area of flagship national parks in America, South Africa, and Australia as a result of changes in policy and practice. Horrific fires have plagued Portugal and Provence from rural land abandonment, and Brazil and Borneo from subsidised transmigration schemes. The lightning-kindled conflagrations that have blistered North America have occurred on public lands; had those places been converted to shopping malls, landfills, or trophy-home suburbs a very different regimen of fire would be likely. And they occurred after policy reforms that sought to increase fire's presence, a goal they achieved though not in the way intended (be careful what you wish for).

All these burns of course share a common chemistry of combustion, all feed upon biocombustibles, and all have drought as a precondition, but none of these factors is either by itself or collectively sufficient to explain the outbreaks. The unifying catalyst is humanity. It would seem that even climate is now bending before humanity's combustion habits. The burned area racked up by megafires, which seems like a proxy of climate change, is in reality an index of climate and people interacting. That this increased burning could, simultaneously, be presented as evidence of both fire management's failure and its success further testifies to the power of fire as a cultural creation.

A fuel array, a habitat, a landscape – nature does not determine by which prism a place might be viewed; culture does. A serious fire scholarship would begin with that irreducible fact.

Conclusion: incurring the wrath of Kuhn

Calls for paradigm shifts are a cliché of our time, as common as the falling of autumn leaves, and anyone who invokes them deserves the righteous wrath of Thomas Kuhn. Most fire scientists will elect to do what they have done in the past. They will surely argue that the three conceptions of fire are really variants of one universal science, bubbling up from a common wellspring of data, that there is no need to parse that collectivity into a suite of thematic models, much less to burden the field with proliferating paradigms. They will insist that the nucleus of research must be fire's physical description, or else science will lose its rigor and its claim to primacy among the several voices of fire scholarship. Persistence forecasting will argue that the near future of fire research will resemble its near past.

This protest misses the point. Each paradigm can claim to survey comprehensively and coherently the whole field; each is fully capable of absorbing the others' data and formulas into its own grander schema; and there may be no way intellectually to assert a transcendent vision over them all. Among them,

arguments can revolve like a game of rock-scissors-paper. Each can declare itself supreme; each can claim its core criteria as fire's true fundamentals; yet none of them is sufficient in itself. A wise fire research program would embrace them all, crafting policies and practices from each according to its abilities, supporting each according to its needs. The physical paradigm works best for firefighting and asset protection; the biological paradigm, for the macromanagement of landscapes and biotas; the cultural paradigm, for defining problems, confirming ideas, and establishing institutions to administer humanity's species monopoly over fire. The value in segregating them is that each can only realise its conceptual potential if it can follow its own internal logic to conclusion. Leaving them to free-associate or merge biases the outcome in favour of the historic default settings – the physical paradigm for research, suppression for policy, and the firefight for narrative.

Fire scholarship deserves better. We are uniquely fire creatures on a uniquely fire planet; that we invest so little in fire's study speaks to a deep disconnect between what we are doing on Earth and how we understand our behaviour. Few topics can speak more profoundly about what it means to be human. Fire offers a synthesis that few other topics can even imagine: every aspect of its expression deserves far more study than we have invested in it. Yet the situation is worsened by the almost exclusive commitment to but one style of analysis, and by the formidable difficulties that would attend any attempt to redirect that momentum. There are too few researchers, and their study too narrow and exclusive.

Almost monthly the chasm widens between what the physical paradigm can do and what the fire community needs. We shape policy and practice to fit what our science can say, not adapt the science to ecological and social requirements. Thus in the United States the determination to have a 'science-based' policy means that projects to restore fire must be framed in terms of 'fuels management' when the issue may be ecological integrity, while arguments over social values regarding nature preserves or exurban sprawl must be translated into fuel loadings that are literally meaningless within the context of that conversation. (Consider as well the arid scholasticism that afflicts the Australian discourse over 'hazard reduction burning.')

The only remediations allowed are to do nothing or to reduce fuels, which is the intellectual equivalent to suppression by mechanical means. Yet the future of prescribed fire will not reside in its role as a flaming woodchipper, but in its capacity as an ecological catalyst. Similarly, the determination of suitable fire policies amid an era of planetary warming powered by anthropogenic combustion habits will not reside in either the physical or biological paradigms, and insisting that it must only wedges research further apart from reality. Too often existing programs are not really investigating the problems: they simply do the science traditional to the field, and when the results prove inadequate, they plead for more funding for more science of the same sort, and then demand that society conform to their research, not research to society. Scholarship thus fails because it is the wrong scholarship, which leaves the field of discussion to raw politics, untethered rhetoric, or the ecological equivalent of faith healing.

It is hard to see how this bias can change, however, until fully biological and cultural conceptions of fire are allowed to flourish as alternative paradigms. It is not enough to go beyond the realm

of today's assumptions but to go beyond the belief that what we need to know can ever be derived from them. The elaboration of alternative paradigms should be a priority task. We need all three; for as with that older fire triangle, remove any side, and the fire will go out.

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