# FINDINGS AND IMPLICATIONS FROM A COARSE-SCALE GLOBAL ASSESSMENT OF RECENT SELECTED MEGA-FIRES

By
JERRY WILLIAMS
Former National Director of Fire & Aviation Management
United States Forest Service
jtwilliams50@msn.com,

DOROTHY ALBRIGHT
Geographer, United States Forest Service
dpalbright@fs.fed.us

ANJA A. HOFFMANN
Biologist, Independent Wildland Fire Specialist
aahoffmann@email.de

ANDREY ERITSOV
Deputy Director of Aerial Forest Fire Centre
Russian Federation
aeritsov@mail.ru

Dr. PETER F. MOORE
Independent Consultant in Natural Resources and Fire Management
peter.moore@blacktreeman.com.au,

Dr. JOSE CARLOS MENDES de MORAIS
Chief, Brazilian Center for Firefighting & Prevention
jose.morais@ibama.gov.br

MICHAEL LEONARD
Strategic Adviser
Bushfire Cooperative Research Centre
mike.leonard@bushfirecrc.com

Dr. JESUS SAN MIGUEL-AYANZ
Senior Researcher
Institute for Environment and Sustainability
European Commission
jesus.san-migue@jrc.ec.europa.eu

Dr. GAVRIIL XANTHOPOULOS
Research Forester, Fire Specialist
Institute of Mediterranean Forest Ecosystems
gxnrtc@fria.gr

Ir. PIETER van LIEROP
Forestry Officer, Fire Management
Food & Agriculture Organization of the United Nations
Rome, Italy
pieter.vanlierop@fao.org

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## ABSTRACT

In many parts of the world, the number of large wildfires has been increasing at an alarming rate. Among them, so-called "mega-fires" have emerged. These extraordinary conflagrations are unprecedented in the modern era for their deep and long-lasting social, economic, and environmental impacts. This paper examines eight mega-fires from around the globe. It attempts to discern patterns in the causal and contributory factors underlying the mega-fire phenomenon.

The cumulative effects of global warming, the vulnerable condition of fire-prone landscapes, and population shifts into and out of wildland settings are changing the calculus of wildfire protection in many countries. As wildfire risks intensify, this paper suggests the importance of more balanced, more comprehensive wildfire protection approaches that better integrate fire-related considerations into natural resource management strategies at the landscape scale. In this respect, mega-fires have important implications for land managers and policy-makers. This paper's findings provide a basis for more effectively aligning land management policies, plans, and practices across fire-prone landscapes.

## PREFACE

This paper was commissioned by the Food and Agriculture Organization of the United Nations under a volunteer arrangement with the authors.

This assessment is not a review or critique of management actions surrounding past wildfires. Nor does it judge the relationship between actions and outcomes. Rather, it is intended to broaden our understanding of the mega-fire phenomenon and identify the factors that underlie these wildfire disasters.

## PURPOSE & NEED

Mega-fires are challenging some of the strongest wildland firefighting programs. The growing number of these incidents, along with the ever-higher suppression costs, property losses, and environmental damages, beg a better understanding of the factors that may underlie their occurrence.

In the past, fire operations specialists, managers, and policy-makers in many places have attempted to match increasing wildfire threats with greater suppression force. This approach, however, is not answering the mega-fire problem. Even in developed countries, where, despite enormous investments in larger, more able firefighting capacity, better predictive systems, increased technology, improved cooperation, and larger aviation fleets, mega-fires still occur. The costs, losses, and damages that accompany mega-fires are going far beyond any threshold of "acceptable loss."

Although mega-fires are often perceived as an "accident of nature," or seen as the result of a failed operational response, or blamed on bureaucratic bungling of some sort, the circumstances under which they occur and the factors that fuel them are not well understood. Typically, most after-action reviews or post-fire investigations limit their focus to operational decisions and actions between the time of detection and time of containment. High-profile incidents may examine preparedness issues, but seldom delve much deeper. This paper looks beyond symptoms to explore the causal and contributory factors that seem to underlie these extraordinary high-risk, high-consequence wildfires. A better understanding of these factors may help guide policy-makers to recognize and more effectively address the mega-fire problem. The growing number of large wildfires and the increasing incidence of mega-fires – along with climate change projections for hotter and drier fire seasons - lend urgency to this issue.

## INTRODUCTION, BACKGROUND, AND CONTEXT

Although catastrophic wildfires dot history's record, most of them occurred before the inception of organized fire control. In fact, today's large, organized wildfire protection programs were often built on the promise of preventing a repeat of such conflagrations. Many of today's wildland agencies can boast a remarkable success rate in suppressing most wildfires, but the magnitude and intensity of a few extraordinary wildfires that cannot be controlled all but defeat the fundamental objective for protection; to minimize costs, losses, and damages. In the United States, only 1 or 2% of all wildfires become large incidents, but they account for about 85% of total suppression-related expenditures and upwards of 95% of the total acres burned (Williams and Hyde, 2009). Similar relationships exist elsewhere. Among all wildfires, mega-fires are the most costly, the most destructive, and the most damaging. Against the backdrop of global warming, their onset may be signaling that many conventional wildfire protection strategies are "running out of road."

China's 1987 Great Black Dragon Fire perhaps marks the beginning of the mega-fire phenomenon in the modern era. This wildfire claimed the lives of over 200 people and burned approximately 1.2 million hectares (Salisbury, 1989). In Indonesia, a succession of extraordinary wildfires in 1982/83, 1994, and 1997/98 resulted in significant ecological damage. Biodiversity losses and greenhouse gas emissions were nearly incalculable on a global scale. Similar effects in Brazil's Amazon region were witnessed over a period of years, culminating with the Roraima fires, also, in 1998. In the United States, since 1998, at least nine states have suffered their worst wildfires on record. In California, a state fielding perhaps the largest, most technologically advanced firefighting force in the world, multiple large fires claimed dozens of lives and destroyed thousands of homes in 2003. In Australia, a series of disastrous bushfires in early 2003, January 2005, and 2006-2007 were exceeded by the February 2009 Black Saturday conflagration; the deadliest civil disaster in that country's history. This disaster killed 173 people and incinerated whole towns. In Botswana, a severe wildfire in 2008 spread onto the second largest game reserve in the world, disrupting a fragile local economy tied to indigenous grazing and the region's important international tourism base. In 2007, severe wildfires hit Greece, making news around the world. Accounts showed people running for their lives against a backdrop of familiar archeological ruins. 84 people died; some near ancient Olympia. This past year (2010), record-setting wildfires in Russia and Israel were added to the list of internationally known wildfire disasters. Across all of Russia, about 2.3 million hectares burned as a result of over 32,000 fires. Sixty-two people perished and hundreds of homes were lost. In Israel, on the outskirts of Haifa, 42 were killed and much of a treasured forest was lost. Over the past several years, similar catastrophic wildfires have occurred in Canada, South Africa, Portugal, Spain, and Turkey among others.

## KEY CHARACTERISTICS OF MEGA-FIRES:

Mega-fires are often extraordinary for their size, but they are more accurately defined by their impacts. Their complexity and their deep, long-lasting social, economic, and environmental consequences make them a serious situation, rather than, simply, a larger incident. Mega-fires are not always a single wildfire, but sometimes a grouping or "complex" of inter-acting multiple fires across a large geographic area. The costs, losses, and damages that come with them seem limited only by the depth of drought, the amount and extent of available fuel, and the extremes of weather.

Mega-fires exceed all efforts at control until firefighters get a favorable change in weather or a break in fuels. Even in countries with modern tools and techniques to combat severe wildfires, firefighters are generally forced onto the defensive; taking action where they can on the fire's terms. Public and political pressures to "do more" are common; no matter how dangerous the situation, nor how slim the chance for control. Managers must be responsive to an anxious public and a demanding media. Someone is to blame and emotions always run high.

Because they burn at landscape scales, mega-fires typically cross ownership boundaries and involve different jurisdictions. Command and coordination functions must accommodate a complex mix of specialists: law enforcement, emergency services, disaster relief, public utilities, and local elected officials...all in addition to rural, volunteer, and urban firefighters.

Mega-fires most severely impact nearby communities, but, they can also have serious "downstream" regional or, even, global consequences. Environmentally, their severity may exceed adaptive limits and interrupt or adversely change energy cycles, water cycles, nutrient cycles, and carbon cycles.

In steep, recently burned-over terrain, scorched, denuded hillsides lay vulnerable to mudslides when heavy rains occur before the land can re-vegetate. Adding insult to injury under these circumstances, it is not unusual for post-fire fatalities and infrastructure losses to approach or exceed those from the fire itself.

By virtue of the fire intensities involved, mega-fires tell us something about increased forest flammability. But, by virtue of the growing numbers of recent fire-related fatalities and climbing wildfire suppression costs, private property losses, and natural resource damages, they call into question the efficacy of conventional suppression-centric wildfire protection strategies. Mega-fires are defeating wildfire protection objectives in many places around the world.

## METHODS

This assessment used a basic root cause methodology to identify causal and contributory factors that may predispose the mega-fire threat.

Causal factors are defined as those that directly precipitate the outcome. In their absence, the outcome would have been avoided. Causal factors include any behavior, act, omission, or deficiency that starts or sustains an accident, incident, or occurrence. In this case, causal factors answer how the mega-fire started.

Contributory factors are more indirect. They are defined as those factors that contribute to – but do not directly cause – an accident, incident, or occurrence. They are often more subtle; representing any behavior, act, omission, or deficiency that sets the stage for the outcome or increase the severity of the outcome (Whitlock and Wolf, 2005). They may be a considerable distance from the cause, but in a wildfire context, they are implicated in the intensity and spread potential of a mega-fire. The root cause methodology asks "why?" at each node in the process, attempting to reveal the next deepest influence underlying the problem. The deepest contributory factors may be difficult to discern, but they often have a significant influence on the scope and complexity of the problem.

The Food and Agriculture Organization enlisted the participation of wildland fire specialists familiar with recent internationally-known incidents in Australia, Botswana, Brazil, Indonesia, Israel, Greece, Russia, and the United States, to compile background information and frame the assessment's findings. These eight countries, from both temperate and tropical zones, represent a diverse cross-section of socio-economic conditions, ecologies, and fuel types on several continents.

A standard questionnaire was provided in order to maintain consistency between respondents. The authors acknowledge that different countries have different means of collecting, storing, and evaluating wildfire-related data. Some are still in the process of sorting things out. Therefore, information surrounding these wildfires often varied in detail. Sometimes information was very limited or unavailable.

Finally, the assessment examined two wildfire protection models where mega-fires have ***not*** occurred. The states of Florida and Western Australia, in the United States and Australia, respectively, offer contrasting wildfire protection examples where, despite the presence of drought, mega-fire risks have been much reduced.

## KEY COMMON FINDINGS AND OBSERVATIONS

The eight mega-fires covered under this assessment are summarized in terms of cause, area burned, and impacts in Table 1. More detailed information is found in appendices A-H.

Table 1. Summary of Recent Selected Mega-Fires (1997-2010)

<table>
<tr><th rowspan="2">Year</th><th rowspan="2">Country</th><th rowspan="2">Name of Fire or Complex</th><th rowspan="2">Cause</th><th colspan="2">Fatalities</th><th rowspan="2">Area Burned (millions ha)</th><th rowspan="2">Suppression Costs (millions US$)</th><th rowspan="2">Property Losses (millions US$) 2/</th><th rowspan="2">Environmental Damages</th></tr>
<tr><th>Direct</th><th>Indirect</th></tr>
<tr><td>1997/1998</td><td>Indonesia</td><td>Kalimantan Complex</td><td>Human (Intentional)</td><td></td><td></td><td>9.7 (region-wide)</td><td></td><td></td><td>- 700 m tonnes greenhouse gases<br>- Land conversion (loss native forests)</td></tr>
<tr><td>1998</td><td>Brazil</td><td>Roraima Fire</td><td>Human (Intentional)</td><td></td><td></td><td>0.011</td><td></td><td></td><td>- Land conversion (loss native forests)</td></tr>
<tr><td>2003</td><td>United States</td><td>Cedar Fire</td><td>Human (negligence)</td><td>15</td><td></td><td>0.11</td><td>32</td><td>2.232 homes</td><td>- Watershed<br>- Endangered species habitat<br>- Recreation</td></tr>
<tr><td>2007</td><td>Greece</td><td>Paleochori - Sekoulas Fire</td><td>Human (negligence)</td><td>36</td><td></td><td>0.04</td><td>5</td><td>-71 homes<br>-6.500 Livestock</td><td>- General forest<br>- Agricultural</td></tr>
<tr><td>2008</td><td>Botswana</td><td>Ghanzi Fire</td><td>Believed human-caused</td><td></td><td></td><td>3.6</td><td>0.24</td><td></td><td>- Wildlife grazing (tourism)<br>- Thatching grass<br>- Livestock grazing</td></tr>
<tr><td rowspan="2">2009</td><td rowspan="2">Australia</td><td rowspan="2">Black Saturday Fire</td><td rowspan="2">Electrical failure (suspicious)</td><td rowspan="2">173</td><td rowspan="2"></td><td rowspan="2">0.43</td><td colspan="3">4,000</td></tr>
<tr><td></td><td>> 2,000 homes</td><td>8.5 m tonnes CO2</td></tr>
<tr><td>2010</td><td>Russia 1/</td><td>Central Russia Complex</td><td>Unknown, likely human-caused</td><td>35</td><td></td><td>0.0677</td><td></td><td>800 homes</td><td></td></tr>
<tr><td>2010</td><td>Israel 1/</td><td>Mt. Carmel</td><td>Human (negligence)</td><td>41</td><td></td><td>0.003</td><td></td><td></td><td></td></tr>
</table>

1/ Compilation of all data not yet complete

[shaded box] Unknown, unavailable or incomplete at this time

2/ Does not reflect indirect losses to community infrastructure or local economies

A wide range of determinants may underlie the mega-fire phenomenon, but in this coarse-scale assessment, several common themes emerged among the diverse range of submissions as the process "drilled down" through the analysis:

**Causal Factors:**

*IGNITION SOURCE*: Nearly all of the mega-fires studied under this assessment were started by people. At least three (Brazil, Indonesia, and Greece) included examples where fires were deliberately set in order to clear land for agricultural or development purposes. In Australia, the Black Saturday Fires were largely due to electrical supply system failures or occurred under suspicious circumstances.

**Contributory Factors:**

*DROUGHT CONDITIONS:* Drought was implicated in all but one of the mega-fires examined in this assessment. The exception was in Botswana where an unusually wet rainy season resulted in an abundant grass crop. During the dry season, this grass crop fueled severe wildfires.

*FIRE WEATHER CONDITIONS:* Hot, dry, windy conditions accompanied all of the wildfires studied here. In fact, all of these fires ignited on (or burned into) extreme fire weather days; the most difficult to control. In many cases, extreme fire weather (i.e. low relative humidity, high ambient air temperature, high wind speed) conditions exceeded previously observed "worst case." Long-distance spotting and very high rates of spread (fire growth) were commonly observed.

*FUEL CONDITIONS and AVAILABLE FUEL:* Dense live fuels and/or heavy, continuous dead and down fuels dominated virtually all of the mega-fire sites studied under this assessment. Often owing to drought, a large proportion of total fuels (dead and live) were available to burn.

In the tropical forest examples, mega-fires were principally fueled by dried-out woody debris left behind from logging and land clearing for plantations and/or crop production. Removal of the native canopy likely accelerated drying in the exposed fuelbed, increasing the amount of total available fuels.

In the temperate zones, on warm, dry sites, decomposition rates are slow. In the absence of periodic underburning, which is often known to have occurred under more natural conditions (i.e. before the advent of attempted fire exclusion), vertical and horizontal fuels accumulated well beyond more natural levels. These over-accumulated fuels significantly added to wildfire severity once they caught fire.

Peat fuels, usually too wet to burn, were particularly problematic in the Indonesia and Russia case examples. Resistance-to-control and smoke production characterized the special problems with peat fires.

*FOREST/SHRUBLAND/GRASSLAND CONDITIONS:* Altered forest conditions were commonly observed across mega-fire landscapes. Alterations resulted from a wide range of acts or omissions. In some cases (Brazil and Indonesia), forest conditions had been altered as a result of intensive logging, land-clearing, and development. Conditions became more flammable when the native canopy was removed and left-over harvest debris dried.

In the Botswana case, the grassland savannah had been altered as a result of a network of fencing, fuelbreaks, and changes in grazing patterns. In this area, continuous grass fuels accumulated across extensive areas.

In the temperate examples evaluated under this assessment, changes in forest structure and composition were commonly observed. Extensively abundant and dense understory biomass, "ladder fuels," and closed crowns often fueled mega-fire potential, under drought conditions.

In Greece, dense forest conditions resulted when resin-tapping, grazing, and other traditional forest uses stopped. Changed land tenures and the loss of traditional practices that once kept fuel accumulations in check were abandoned as people moved away for improved economic opportunities elsewhere.

In Australia, Greece, Israel, possibly Russia, and in the United States, efforts to exclude fire and limit disturbance resulted in the build-up of continuous, homogeneous fuelbeds. These conditions often contributed to uncharacteristically high fire intensities.

Note: In several of these countries, fire specialists have observed that earlier hazard mitigation treatments in or adjacent to mega-fire perimeters have slowed or arrested the spread of running, high-intensity wildfires. In places where understory thinning, selective harvest, and/or prescribed burning reduced fuel loads, forest resilience was much enhanced. In fact, many of these stands survived the passage of high-intensity wildfires.

*LANDSCAPE HOMOGENEITY:* In the tropical forest types, homogeneous, undisturbed conditions seem to deter the growth of large wildfires. Owing to more wet, humid conditions, undisturbed forests in the tropics are largely fire proof. Mega-fire potential increases only when severe disturbance (e.g. intensive logging or land clearing) coincides with drought, extreme fire weather conditions, and multiple ignitions.

However, in fire-prone more temperate vegetation types, mega-fire potential seems largely predicated on landscape homogeneity; the extent of continuous available fuels. While several factors may influence landscape homogeneity, in this assessment climate and history of disturbance seemed to predominate.

In a cool/wet climate cycle, natural moisture differentials (in naturally regulated temperate forests that burned at frequent intervals) were probably more diverse; in that the landscape was represented by more "patches" of stands with different ages, different structures, different species, and different fuel loads.  These differences may have acted to leave some areas relatively safe from burning during the fire season.  Spread potential and/or fire intensity from subsequent fires may have been limited by this landscape diversity, even under drought conditions.  Certainly, wildfire behavior that is observed today around many of the "patches" prescribed burned beforehand tend to support this reasoning.

In this assessment, most mega-fire landscapes did not demonstrate much diversity, in terms of terms of age-class distributions, vegetative structure or species composition.

Under severe, prolonged drought, moisture differentials all but disappear, as all aspects and all elevations along the moisture/ temperate gradient dry out.  Together with drought, the absence of vegetative diversity may be exacerbating the potential for mega-fires by further reducing an important flammability differential.

Dry, densely arranged, homogeneous aerial and surface biomass fueled many of the mega-fires evaluated under this assessment.  In Australia, Botswana, Israel, Greece, and the U.S., the absence of landscape "patches" or "mosaics" was judged an important contributing factor to mega-fire potential.

Note:  This observation may be most critical in those places where volatile fuel types and people are "sandwiched" between a hot, dry landmass and a much cooler large body of water.  These are areas where intense gradient winds typically develop, as were observed  in Australia, Greece, Israel, and  the U.S..

*LAND-USE EMPHASIS and LAND MANAGEMENT POLICIES, PRACTICES:*  Mega-fire potential seems highest where forest practices result in forest conditions that are furthest outside the natural range of variability.  Mega-fires evaluated under this assessment tended to occur at the extremes of forest management.  That is; they were most common in places where, either, severely disturbed (exploitation) or altogether un-disturbed (preservation) practices were being emphasized.

In the tropics, conflagration fires were largely confined to exploited logged-off areas, where extensive land-clearing left behind large volumes of available fuel.

In the drier, temperate forest types, mega-fires were observed in places where prolonged fire exclusion practices were coinciding with land management strategies favoring un-disturbed conditions.  In the Greece case, the land had been abandoned and left un-attended.  With natural disturbance processes excluded and the land being managed for undisturbed conditions, often to preserve values, live and dead fuel build-ups resulted on these mega-fire landscapes.  During drought episodes, these increased available fuels added to fire intensity levels and, paradoxically, put at risk the very values the preservation objective was attempting to sustain.

Note:  In several temperate countries, most historic conflagrations occurred at the other extreme in land management, where forests were being exploited.  For example, the deadliest wildfire in the United States was largely the result of "high-grade" harvest and "slash and burn" practices that were common in early logged-over forests.  The Peshtigo Fire (Wisconsin, 1871) burned some 607,000 hectares and killed between 1,200-2,400 people during a severe wind event.

Mega-fire risk seems particularly high where land-use objectives are at odds with the site's disturbance ecologies and fire regime dynamics.

Among the eight mega-fires examined under this assessment, wildfire protection programs ranged from non-existent to suppression-centric. It should come as no surprise that mega-fires would overwhelm those units with little or no wildfire protection capability. However, this assessment found several examples where highly capitalized wildfire protection programs were ineffectual against the mega-fire threat.

Note: In Australia, Greece, and Russia rural (often volunteer) firefighting forces with local knowledge are declining in number. Israel has no dedicated wildland firefighting force. While forest management skills are being de-emphasized, there is a tendency for some governments to increasingly rely on urban-based firefighters and/or rural-based volunteers. These changes may be overlooking the importance of forest management skills in mitigating the fuel hazards that predispose severe wildfires.

*GOVERNING LAWS, POLICIES, AND PLANS:* Perhaps ironically, in many places, governing wildland laws and policies may be impeding more effective wildfire protection capabilities as fuel hazards grow, drought deepens, and wildfire risks climb.

In Australia, the United States, and elsewhere environmental concerns for air quality, endangered species habitat, water quality, and other values are protected by law. As applied, the law often aims for undisturbed conditions. Preservation aims often rely on suppression-centric protection strategies to maintain current conditions. As droughts intensify and flammability potential compounds, it is proving more costly and less feasible to sustain suppression-centric protection strategies in these places. As mentioned above, preservation strategies may be imperiling the very values they were intended to save in un-disturbed fire regimes under drought conditions.

In Greece, prescribed burning remains banned altogether. Meanwhile, land development laws that protect forested areas are circumvented by arsonists when burned-over lands no longer qualify as "forested." Furthermore, the use of fire to fight fire is not employed. Firefighters are left to resort to indirect attack methods which, under extreme burning conditions, leave them with little chance of success.

In other developed countries, strict air quality and other regulatory controls effectively limit fuel hazard mitigation efforts, including prescribed burning.

After-action reviews or post-fire investigations seldom recognize or address high-hazard land management or land-use practices, where many destructive wildfires incubate.

## CONTRASTING WILDFIRE PROTECTION STRATEGIES

Although drought is often blamed for the onset of mega-fires, Florida and Western Australia offer two examples where, despite the prolonged presence of severe drought, wildfire costs, losses, and damages seem much lower than elsewhere. These programs reflect more balanced prevention, mitigation, and suppression approaches. When compared to more suppression-centric examples, they emerge as places where mega-fires do not occur. In fact, they offer examples where mitigation treatments have stopped mega-fire spread coming off of untreated lands.

Both Florida and the southwest of Western Australia can (and do) experience difficult wildfires, but they tend to occur where prescribed burning is not widely used.

In Florida, the U.S. Forest Service and the State of Florida have a combined ownership of approximately 800,000 hectares. On average each year, both agencies prescribe burn between 10 and 20% of their holdings. Prescribed burns occur on a 2- to 4-year rotation. Prescribed burning costs range from about $US10-30 per hectare in these areas. In forests left untreated, wildfire suppression costs can often exceed many hundreds, even thousands of dollars per hectare, not counting the additional losses and damages that may be involved).

In southwest Western Australia, the Department of Environment and Conservation protects an estate of approximately 2.5 million hectares. It routinely uses prescribed fire to treat approximately 8-9% of their holdings and aim for 70-90% burn coverage. Prescribed burn projects are strategically placed and treated at planned intervals. Wildfire costs, losses, and damages have been much reduced since the prescribed burning program began, following the Dwellingup Bushfire disaster in 1961.

In some areas, community-based fire management initiatives are underway. These models, made up of participants from among private and public landowners, often provide the means to strengthen cooperative efforts, reconcile competing interests, and provide for safer and more resilient fire-prone forests at landscape scales.

## KEY CONCLUSIONS

The reasons behind mega-fires may be as diverse as the cultures, economies, histories, and ecosystems as the countries within which they occur. Certainly, these factors vary widely across temperate and tropical forest types and between developed and un-developed countries. Understanding these factors in the context of fire disturbance regimes is fundamental to understanding the mega-fire threat. The science in all of these places may not yet be fully settled. However, it seems likely that mega-fire risks increase as droughts deepen, fuels accumulate, and landscapes become more homogeneous.

- With the onset of more pervasive, world-wide drought, there is no longer the assurance that some places, only because they have not had severe wildfires in the past, will be safe from conflagrations in the future.

- The majority of mega-fires were caused by people. At least two were set intentionally for an expected localized benefit. Both of these incidents, because they had severe "downstream" adverse effects, were categorized as mega-fires in this assessment.

- In the tropical forest case studies, mega-fires resulted when the forest cover was removed. Severe fire behavior was fueled by dried-out woody debris, left behind after "high-grade" logging, land-clearing, and other exploitive practices.

- In the arid woodland-savannah case (Botswana), a mega-fire burned through a network of fences (and some fuelbreaks) intended to control grazing and wildfires. The absence of these disturbance influences over a long period resulted in the development of an abundant and extensive fuelbed.

- In the dry temperate forest and brush-land examples, mega-fires occurred in dense fuel beds across largely undisturbed, homogeneous landscapes, where preservation strategies emphasized "hands-off" land management.

- In virtually all of the tropical and temperate case examples, land management and/or land-use actions or omissions (intentional or not) carried significant wildfire-related risks that were not anticipated at the scope and scales that resulted.

- The direct impacts resulting from mega-fires were often enormous. However, their indirect effects may be far greater. These second-order effects to human health, infrastructure, and local economies are barely accounted and rarely documented. Environmentally, water quality, soil quality, and endangered species habitat are, also, often overlooked when assessing post-fire impacts on a long-term, cumulative basis. Declines in biodiversity, "black carbon" emissions, and invasive weeds may be of special concern.

- Massive amounts of carbon release were documented on some of the mega-fires examined here. In several countries, wildfire emissions are exempt from regulatory controls. Because $CO_2$ emissions contribute to global warming and mega-fires are the result of drought, mega-fires (and carbon releases) may represent a dangerous feed-back loop that becomes self-perpetuating in the absence of stronger wildfire emissions monitoring and control. Little is known of this possible iterative relationship and its long-term ramifications.

- In several cases, governments are attempting to confront increasing wildfire threats with greater suppression force. There seems a tendency for some governments to rely more and more on urban-based firefighters and/or air-attack assets, but, despite the escalating costs involved, the approach is proving largely ineffectual. A coincident decline in forest management skills appears to be exacerbating the problem.

- In many cases, the data required to better understand causal and contributory factors is incomplete or unavailable. As a result, many places cannot integrate even a basic understanding of fire disturbance dynamics into wildfire protection programs, land management plans, land-use policies, nor the environmental laws that they all rest upon.

- Mega-fires are not occurring where land management practices are consistent with the fire ecologies and disturbance dynamics that define the ecosystem. Mega-fire risk is likewise much reduced in those areas where wildfire protection programs are more balanced between prevention, mitigation, and suppression elements.

*"Everything is simple in war, but the simplest thing is difficult."*
*-Carl von Clausewitz*

**SUMMARY**

Mega-fires need to be understood, instead of dismissed as anomalies, accepted as unavoidable accidents of nature, or faulted as a failure of response. If we look deeply enough, they tell us something about our own complicity in their onset.

Certainly, drought sets the stage and human negligence may provide the spark, but vulnerable vegetative conditions are fueling the mega-fire threat. In exploited tropical forests, "high-grade" logging, land clearing, and wholesale site conversions have left high volumes of slash and debris behind. In many fire-prone temperate forests, where undisturbed conditions are favored as the means to preserve values, continuous fuels and biomass have accumulated over extensive landscapes. Both scenarios, waiting on drought, incubate the next wildfire disaster.

At its root, the mega-fire phenomenon reflects a significant land management issue. Specifically, mega-fires are indicating that land management strategies in fire-prone ecosystems are often in contradiction to the disturbance regimes and ecologies that define these landscapes. These contradictions leave fire-prone forests less resilient and predispose mega-fire risks in the presence of drought.

Often, mega-fires further trace to forest management laws, regulations, and policies that may no longer be achieving their intended aim. The regulatory controls that "worked" in a cool, wet climate cycle may now be imperiling the values that they were intended to save as drought takes hold.

It is not clear that governments have recognized or responded to the mega-fire problem, its root causes, and its contributory factors. Most attention remains directed at the symptoms.

In some places, efforts are underway to "harden" houses and invest in bigger, faster, stronger fire suppression capacity. In other places, some argue to "let nature takes its course" and let wildfires go. Until the root causes and contributory factors underlying the mega-fire phenomenon are more broadly acknowledged and acted upon, it is uncertain that either approach will work. Recent experience indicates that wildfire suppression costs, private property losses, and environmental damages will continue to climb in the absence of more balanced, more comprehensive landscape management strategies. Without an ecological context, unintended consequences may metastasize in ways that we cannot anticipate. In the absence of change, those at risk may almost certainly need to recalibrate their measure of "acceptable loss." In this, the United Nations' "Year of the Forest," the onset of mega-fires should challenge governments around the world to adapt wildfire protection programs to confront causes and contributory factors; not chase symptoms.

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- United States Support: Carlton Joseph (Forest Fire Management Officer, Cleveland N.F.), Rich Hawkins (Forest Fire Management Officer, Cleveland N.F., retired), and Neil Sugihara, Fire Ecologist, U.S. Forest Service, Pacific Southwest Region. Also, Dale Dague (U.S. Forest Service Branch Chief for Disaster & Emergency Operations, International Fire) and Tom Harbour (National Director of Fire & Aviation Management, U.S. Forest Service, Washington). Also, Jim Karels (Florida State Forester) and John Saddler (Florida State Forester's Staff) and Clint Cross (U.S. Forest Service Fuels and Fire Use Specialist, Southern Region)

**APPENDICES:**

**Appendix A.** ***Australia*** (compiled by Mike Leonard)***:*** The 2009 Black Saturday Fires (Victoria, SE Australia) were a grouping of several large fires. Some burned together. They followed a 13-year period of drought. Over the period when these fires occurred, the area was experiencing the most severe and prolonged fire weather on record, with extreme ambient air temperatures (> 43 degrees C) and very strong winds. The most deadly of the fires is believed to have been caused by faulty power lines; others occurred due to power supply faults or under suspicious circumstances. Many originated in more remote areas of the public estate. They burned approximately 430,000 hectares in a 14-day period, running onto private lands. The fires killed 173 people, most on one day, following a severe wind event. The fires damaged or destroyed over 2,000 homes. The suppression costs, private property losses, and natural resource damages exceeded $US 4 billion. It was estimated that over 8.5 million tonnes of carbon dioxide was released into the atmosphere as a result of the 2009 Black Saturday Fires. One can only imagine cumulative emissions, considering that, in the State of Victoria alone, close to half of all native forests and woodlands have burned between 2002 and 2010. Australia's history is marked with numerous high-cost, high-consequence wildfires; many involving multiple fatalities.

In the recent past, the Victorian Alpine Fires (2003), the Capital Territory Fires that burned into Canberra (2003), the Wangary Fire on South Australia's Lower Eyre Peninsula (early 2005), and the Victorian Great Divide Fires (2006-2007) are among the worst. However, they pale when compared to the Black Saturday Fires; these became the nation's deadliest civil disaster on record. Eucalypt fuels dominated the general fire area. On private lands, crops, pasture, wineries, and other agricultural values were burnt or threatened. Town sites and small communities were lost. Tourism, wine-growing, and other local economies were devastated, as a result of the catastrophe.

**Appendix B.** ***Botswana*** (compiled by Anja A. Hoffmann)***:*** A total of nearly 12 million hectares burned in Botswana during the 2008 fire season. In the central Kalahari, single large-scale fires have occurred as recently as 2002 and go back to the 1970's. However, the 2008 Ghanzi Fire was the most consequential on record. It was believed to have been person-caused, originating in a wildlife management area, close to an established settlement. Grassland savannah fuels dominated the fire area. Unusually abundant rainfall leading up to the fire season resulted in very high grassland fuel loads across the general area. The fire season was very dry, as is typical. The fire burned over 3.6 million hectares during a 50-day period, across a mix of land ownerships. Much of the land was managed for grazing (both domestic livestock and wildlife) across tribal lands, commercial ranches, and game reserves in National Parks and Wildlife Management areas. Among local communities, thatching grass collection was the main income-producing activity. A large network of fences influenced grazing patterns throughout the area. A long-in-place fencing effort has effectively limited the range of large wildlife herds, resulting in a larger contiguous buildup of grass fuels with less landscape "patchiness." On the Ghanzi fire, greater grass fuel loads contributed to higher-intensity, less controllable wildfires with greater spread potential. Homogeneity of the fuelbed was also due to the lack of numerous smaller fires that, under more natural conditions, might have burned themselves out against recent grazed-over areas or other recent burns. In modern times, fuelbreaks have been the principal means of controlling fire. In 2008, however, fuel break construction was delayed well into the fire season. As a result of these wildfires, about 75% of the wildlife reserve was burned over. Most of the damages involved at least one season's loss of grazing and adverse impacts to the local and regional economy, including those to tourism. Costs, losses, and damages were estimated at $US 239,000, a considerable sum relative to the economy in this area. This area's fragile economy made this wildfire particularly devastating to local communities depending on seasonal income.

**Appendix C.** ***Brazil*** (compiled by Dr. Jose Carlos Mendes de Morais)***:*** Roraima State, in the north-central Amazon region, has been affected by extraordinary drought-induced wildfires as recently as 2001 and 2003, but the 1998 fires remain the worst on record. These fires were person-caused and intentionally ignited for land-clearing purposes. Agribusiness is the dominate land-use activity in the area. These wildfires burned out of control for over 30-days, covering some 11,000 hectares. A severe drought, accompanied by high ambient air temperatures (>40 degrees C) and strong winds fanned much of the burning. Because wildfires are often self-limiting in humid tropical forest types, organized firefighting assets have not typically been locally available in this area. They were brought in from neighboring states under Brazil's national system for forest fire protection. These assets reinforced local volunteers, associations, and public officials. Smoke impacts, affecting nearby population centers, were among the most significant adverse effects. Other damages were related to forest mortality; mostly among trees smaller than 5 cm diameter. Much of the overstory survived. No fatalities were reported. Improvements in an organized firefighting response were credited with preventing a repeat of the 1998 disaster, when the severe years of 2001 and 2003 again hit the area.

**Appendix D.** ***Greece*** (compiled by Dr. Gavriil Xanthopoulos)***:*** In 2007, Greece experienced its worst wildfire season ever, following a deep drought and at least two heatwaves. A total of 270,000 hectares burned and 84 lives were lost over a period of about 7 days in the end of August, when severe fire weather conditions (low humidity, high ambient air temperature, and high winds) contributed to rapid fire growth. Two of the wildfires (Paleochori and Sekoulas) burned together, claiming 36 victims. This wildfire, 200 km west of Athens, burned approximately 40,000 hectares. Although the majority of acres burned occurred on public lands, 67 villages were affected, destroying over 71 homes in Makistos and Artemida, alone. Dozens of additional homes, along with hundreds of stables, warehouses, and outbuildings in other villages were also destroyed. More than 6,500 goats and sheep were killed as well. At least $US 5.5 million were expended to suppress this fire. Grass, evergreen shrubs, and pine forests were the dominant fuels in the area. Fuel build-up, owing to several years of changing land tenures, decline in grazing practices, and the loss of an "agricultural mosaic" predisposed the area to very large-scale wildfire potential. Prescribed burning is excluded in Greek law, as a means of managing forest lands.

Economic and organizational changes also appear to have affected the 2007 fire outcome. Some forest-based rural economies collapsed following Greece's admittance into the European Union. Resin tapping in the region's pine forests, for instance ended, taking with it a workforce that moved on for opportunities elsewhere. The forests were generally left unattended and a younger local workforce having a stake in its protection disappeared. Also, in 1998, rural firefighting responsibilities transferred from the more rural-oriented Forest Service to the more urban-oriented Fire Service. This move strengthened mechanization capabilities (including aerial assets) and established a suppression-centric wildfire protection program emphasizing direct attack methods. The move diminished the role and capacity of forestry and forest workers. Although the Fire Services, up to this point, demonstrated firefighting success on lesser wildfires, the fire behavior associated with these catastrophic wildfires exceeded all efforts at direct control. Line production rates (including those of aerial attack assets) were altogether inadequate against these fires' rates of spread. There were isolated examples where backfiring and other agile "guerilla" tactics were used to save property, but most were credited to the remnants of the rural Forest Service.

**Appendix E.** ***Indonesia*** (compiled by Dr. Peter F. Moore)***:*** The 1997/98 Indonesian fires were person-caused. They were ignited for large-scale land-clearing for pulp and oil palm plantations. There were no reported fatalities. Altogether, they burned over 9.7 million hectares in a diverse mix of tropical forest types, timber plantations, and estate crops. Previous similar-scale fires occurred in 1982/83 and in 1994. Hundreds of intentionally lit fires moved onto secondary or degraded forest lands unintentionally, under the influence of drought. The ignition of peat was particularly problematic. Little to no suppression actions were taken. Because the consequences of these wildfires impacted regional neighbors and the global community, most of the wildfire-related concerns were expressed by non-government organizations and groups external to Indonesia. Approximately 700 million tonnes of greenhouse gases were released into the atmosphere as a result of these wildfires, making them one of the largest pollution sources in the world. It is recognized that the use of fire to clear land and prepare sites for timber and agricultural production are significant to the Indonesian economy. The benefit:cost balance was asymmetrical, in that segments of the country actually benefited from the activity, while the costs were born by other segments of the population or were widely dispersed outside of the country.

**Appendix F.** ***Israel*** (compiled by Dr. Jesus San Miguel-Ayanz)***:*** Few details are known about this fire, at this time. In December 2010, 41 people were killed as a result of fast-moving wildfire on Mount Carmel, near Haifa. The fire was the result of negligence. Although the fire's size was limited to 3,000 hectares, in this arid region, the loss of forest cover was devastating, both environmentally and culturally.

**Appendix G.** ***Russia*** (compiled by Andrey Eritsov)***:*** The 2010 wildfire season in Russia was the most extreme since 1972. Nationwide, about 2.3 million hectares burned as a result of 32,300 fires. Across 19 regions of the country, more than 2,000 homes burned in over 100 villages. Sixty-two lives were lost, including those of three firefighters. In European Russia, the 2010 fire season was the worst on record. A severe drought combined with record-high temperatures and strong winds between 21 June and 19 August. It is believed that most of these wildfires were caused by carelessness. The general area was represented by conifer and mixed forests, with some areas of peat bogs. The smoke impacts to Moscow, Nizni Novgorod, Cheboksary, and other areas lingered for weeks and, along with the heat, caused pulmonary problems among the population. Russia responded to the wildfire emergency with over 200,000 firefighters, 30,000 trucks and engines, and about 200 aircraft. Fourteen other countries provided assistance. All villages were re-constructed under a government program by 1 December 2010.

Note: Table 1 in this report reflects the impacts from several complexes in Central Russia during the 2010 fire season. Impacts are summarized from the Republic of Mordovia, the Riazan oblast, the Nizni Novgorod region, and the Moscow region.

**Appendix H.** ***United States*** (compiled by Dorothy Albright)***:*** The 2003 Cedar Fire, outside of San Diego was person-caused. It ignited on public lands during a large fire emergency occurring throughout Southern California during a Santa Ana wind event. Some 110,578 hectares burned over a ten-day period on the Cedar Fire. The fire killed 15 people (including one firefighter), destroyed 2,232 homes and 588 structures, and cost over $US 32.7 million to suppress. The fire followed several years of drought and was influenced by a high dead-to-live ratio in the live fuels and severe fire weather conditions (single digit relative humidity, high ambient air temperature, and strong winds). Although California has a long history of devastating wildfires, including some since 2003, the Cedar Fire remains the worst on record. The fire area included a mix of public and private lands. On public lands, watershed values, recreation values, and critical wildlife habitat were represented. Large, well-coordinated wildfire suppression capacity is the basis for a land management strategy intended to preserve these values. Fuel reduction burning was routinely used to control the buildup of fuel in a small conifer-dominated recreation area, with positive post-fire results. However, in the more extensive chaparral and coastal sage fuels, prescribed burning was limited. In these fuel types, ecological concerns, endangered species concerns, air quality concerns, risk of escape, and, more lately, questions about its effectiveness as a suppression aid, have limited its use at meaningful scales. Hazard mitigation strategies have recently shifted from age-class diversity burning in brush fuels (at relatively small scales) to intensive fuel reduction practices on the wildland-urban interface perimeter where homes and private property abut public lands. In some places, fuel reduction burning has been complemented with FIREWISE building practices for new home construction, as the principal means to protect private values. Wildfire protection strategies continue to rely on a rapid and aggressive suppression response. Although the strategy aims at protecting private and critical natural resource values, it is unclear the long-term ramifications to these values when suppression efforts fail and very large wildfires occur. Very large-scale vegetative type conversions (e.g. chaparral to non-native grasses and invasive weeds) are being observed where person-caused high-intensity fires have recurred at short intervals. Summertime wildfires have given way to more late-season wildfires that coincide with drier, windier, and more severe fire weather conditions. While the immediate urgency to protect homes and private property dominates the Southern California wildfire problem, the science to support ecologically appropriate, longer-term solutions remains unsettled.

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