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The Australian wildfires from a systems dependency perspective

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Introduction

Wildfires are a normal occurrence in much of the world, with many fire adapted ecosystems and societies (Moritz et al. 2014). However, a number of drivers appear to be increasing the fire risk and propensity for losses globally (Anon 2019). These drivers include global climate change which through heat and drying is increasing landscape flammability (Podur and Wotton 2020; IPCC 2019; Jones et a. 2020). Exposure is being exacerbated through increasing use of fire prone landscapes for urban development, infrastructure and related activities. There is also widespread farmland abandonment, with the consequent loss of land and fire-risk management (Komac et al. 2020). Importantly, there are now indications that wildfires are increasingly characterized by severe ecosystem impacts (Lewis 2020). While smaller wildfires often have a rejuvenating effect, the catastrophic fires recently seen in Australia, US and Indonesia seem to leave some ecosystems very seriously damaged (Duncombe 2020; Ward et al. 2020). This also has important socio-economic implications, including health, tourism and economic development. How to assess and deal with extreme wildfire risks in the future is a key question that needs to be addressed at the local, country and even global level.

The recent Australian wildfires provide the starting point for a discussion on ways to move forward. Firstly, the wildfires showed how compound climatic events can cause unprecedented large-scale impacts: the combination of the long-lasting record high temperatures with record low precipitation across Australia provided the extreme conditions necessary. Polls on fire impacts showed that nearly 60% of those surveyed were directly affected by the fires, with an extraordinary 80% of all Australian residents being affected in some way (Biddle et al. 2020). Secondly, the spread and scale (Boer, de Dios, and Bradstock 2020) of wildfire impacts was due to an increase in dependency of risk between regions: not only did the weather events cause an increase in risk at local levels, they also caused an increase in very large-scale wildfire risk due to spatial dependencies (Figure 1). Thirdly, there are data scarcity and quality issues relevant for a systems approach, e.g. most Australian data comes from frequent small-scale events which does not say much about how the system behaves under extreme conditions (Bowman 2018). This has important implications for policy implementation, as fourthly, current strategies are inadequate for such fires especially for some of the severe systemic impacts with ecosystem services and economies as they are not incorporated explicitly.

To expand on the last point, the current approach relies primarily on fuel reduction for prevention, with an increasingly high tech fire-fighting capacity to contain fires and reduce losses, and public preparedness. In the recent fires, suppression had limited success, with one fire burning for 79 days. There is also increasing attention to planning and building regulations, especially at the urban interface and coastal holiday towns. These options work reasonably well with low to moderate intensity fires, but when conditions are severe, weather becomes the controlling variable rather than fuel (Penman et al 2019). Fire-fighting is unable to suppress fires in extreme weather conditions, and the effectiveness of planning and building controls is not yet clear either. It should also be mentioned that very substantial increases in planned burning for fuel reduction generate smoke related health hazards and other risk issues. In the 2019-20 fires the damage caused directly by the fire was only part of the story – the associated smoke resulted in health and major economic impacts for much of the nation – even for locations far from the fires (Borchers Arriagadda et al. 2020). Fire and emergency management in Australia (and most of the world) is not equipped to deal with systemic risks and impacts that cascade through communities, economies and ecosystems. It is worth mentioning that while Australia may be a resilient nation, the economies impacted were not doing well, and many ecosystems were very stressed by long running unprecedented heat and drought.

Catastrophic wildfire events will happen again and new management strategies are therefore needed for at least two reasons: (i) compound events such as occurred in Australia may experience tail dependency and (ii) such extreme weather events may also cause high spatial dependence of wildfire risk. We argue that by adopting a systems perspective both types of dependencies are explicitly taken into account, thus enabling the integrated management of small scale as well as large scale wildfire risks within a coherent framework. We define a system to be a set of interconnected elements (e.g. geographical areas, decision makers, climate-related risks, risk drivers etc. see Figure 1) within a defined system boundary. We discuss ways of dealing with such events using the Australian wildfires.

Tail and Spatial Dependence of Wildfire Risks

Drawing on the IPCC risk framework (SREX 2012) Zscheischler et al. (2018) suggested a system-centric approach (similar to our definition above) and defined compound events as "a combination of multiple drivers and/or hazards that contributes to societal or environmental risk". This is what was seen in Australia last summer following a year of weather records. Worryingly, such situations are likely occurring more frequently than previously expected under a changing climate.

Also important is the possible increase in tail dependence (Nelsen 2006). Tail dependence occurs when there is an increase in correlation of risk for events that lie in the tail of the distribution, i.e. for extremes. If tail dependence is not accounted for, the probability of extreme compound events can be seriously underestimated (Bevacqua et al. 2017). For example, treating individual phenomena, such as temperature and precipitation, as independent from each other may substantially underestimate the risk of very extreme events; e.g. the probability of low rainfall may be much higher when there is extreme rather than normal temperature in a given area. There are many reasons for this, but are usually case specific (see Zscheischler et al. 2018 for a summary). For example, the Australian fire danger index (FFDI) includes temperature and precipitation as well as a "drought factor" based on soil moisture for fuel availability. However, it does not include critical factors such as wind changes, atmospheric stability(Boer et al. 2017), or the potential for pyro-cb fires (Pyrocumulonimbus thunderstorm clouds triggered by fires in extreme conditions) (Bowman et al. 2020), nor does it integrate extreme weather and dryness conditions. Pyro-convection fires were rare in Australia, but are now common and underlie many of the severe fire impacts, as they create severe weather conditions preventing use of aircraft and making fire behavior unpredictable (McRae 2018). Furthermore, while the index works well in low intensity conditions, it is unable to gauge the risk of catastrophic fires in today's environment - which is why much effort is going into developing a new index (Yeo et al. 2014).

Perhaps most importantly, the spatial dependence between risks may also change dramatically with accelerating climate change (Gaupp et al. 2020; Jongman et al. 2014). For example, the unprecedented dryness in Australia before the wildfires increased the risk of fires spreading rapidly and extensively, and made them harder to control. The mechanism causing spatial dependencies is different for each climate-related risk, but for wildfires it is usually the dryness and amount of flammable fuel. Winds are also key for wildfires as they spread embers which ignite other areas. However, (referring to Figure 1) while during normal times extreme dryness will vary in different areas (left hand side) during long-term high temperature and low precipitation episodes, the dryness will be extreme everywhere – a form of spatial correlation (right hand side). Consequently, the risk of large-scale wildfires will be much greater than previously anticipated for at least two reasons; the higher probability of compound weather events, and the higher spatial dependencies of risk such events create.

Methodological considerations for assessing tail and spatial dependencies

The Copula technique (Nelsen 2006) has become the method of choice for assessing spatial and tail dependencies in an integrated manner, but is seldom employed for wildfires (Xi et al. 2019). Copulas are capable of providing an answer to the following question: given one risk realizes, what is the probability that another risk realizes as well. This setting can refer to weather risks (e.g. temperature and precipitation) but also to spatial dependence (risk realization in different areas). If it is true that for extreme (including compound) events different dependencies (magnitude wise as well as spatial linkage) need to be assumed than in normal times, then a change in the system perspective regarding the system boundaries and scope, is needed for event management. This situation, that small wildfires are quite different from very large ones, is well illustrated by the recent wildfires in Australia. Dependencies may act as the guiding principle not only for assessing wildfire risks but also for evaluating risk management options. The two most extreme cases of a system state would be independence and full dependency with a continuous scale between the states (based on Hochrainer-Stigler et al. 2018). The dependency can be measured using the copula approach or other dependency measures (e.g. Kendall's Tau or DebtRank) (Figure 1). For example, DebtRank (Battiston et al. 2012), the most prominent systemic risk measure in finance today, estimates the impact of an elements default (e.g. a local fire in our context) on the rest of the system. It is a measure inspired by the notion of network centrality and accordingly, DebtRank can be considered as an early-warning indicator for an element being too central to fail. In the case of a copula approach, the copula parameters themselves can be used to determine in which system state one may belong too. For example, using a Clayton copula (Nelsen 2006) a parameter of zero would mean that the system state would belong to the no-dependency system state while an increase of the parameter would indicate that it belongs to the dependency system state (see Hochrainer-Stigler et al. 2018).

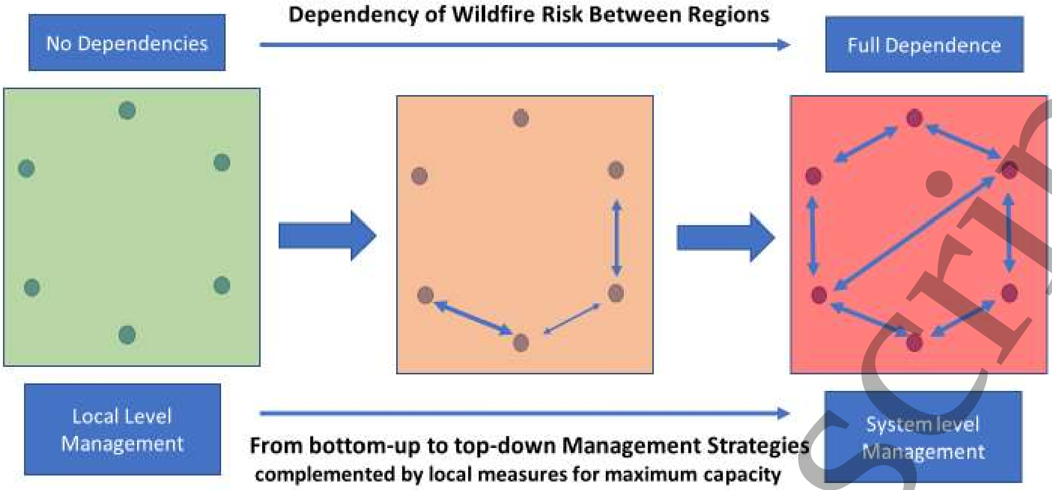

Figure 1: Local states (dots) and system level (square) wildfire risk on a continuous scale based on the spatial dependency (arrows) of wildfire risk between local states. The larger the dependency between states, the more a system level management is additionally needed. Based on Hochrainer-Stigler et al. 2018.

Integrating Top down and Bottom up Wildfire Risk Management Approaches

Wildfires will occur with certainty. The questions concern whether they spread across regions due to increases in tail and spatial risk dependencies, and in which system state such catastrophic wildfires would occur. For small wildfires that may be less able to spread (e.g. because of fuel moisture), the dependency between different regions may be small and wildfires in one region can be controlled with current wildfire management strategies (left hand side of Figure 1). However, for situations where wildfires can spread uncontrollably across regions, there needs to be an institution or arrangements for dealing with this risk at a larger (e.g. state, national or even continental) system level (right hand side of Figure 1). This broader systems perspective has implications for dealing with wildfires at both the local and national levels. Focusing again on tail and spatial dependencies as crucial determinants for more comprehensive wildfire management, the decision makers at the higher system level (e.g. national) would deal with the dependent risk (also called systemic risk in case that risk realizes under a high dependency scenario): for large scale wildfires the focus would be on reducing tail and spatial dependency (i.e. moving risk to the left hand side of Figure 1), which would allow local decision makers to continue focusing on managing risk at the local level, assuming independence from other regions.

For taking wildfire risk management to a new level, we suggest a risk layering approach as an adaptive risk governance framework (Linnerooth-Bayer and Hochrainer-Stigler 2015; Mechler et al. 2014). This may be especially useful if tail and spatial dependencies are to be considered. This means that for more frequent fire events, where locally restricted impacts dominate, practitioners can still rely on fire management options currently employed. For higher layers of wildfire risk, where we experience high tail and spatial dependence, novel strategies that go beyond business as usual measures will need to be developed – and this extends to research where different approaches are also needed. For example, risk diversification through modularization (e.g. decreasing the connection between local states) is often suggested in systems with high dependencies (for a detailed discussion see Helbing 2013) and could be also in the case of wildfire risk one viable way forward. Risk prevention seems most important for the case when high dependency (and systemic risk, as many regions are affected at once) dominates. Decreasing the possibility of spatial connection, and therefore wildfire dependencies between regions, through e.g. landscape and asset risk management, is one way forward. In Australia, the largely top-down command and control approach expands capacity through overseas fire-fighters and military and use of Australian army reservists. This option is expensive and has limits. We suggest complementing this top-down approach with a more streamlined approach of integrating the locally available risk prevention and management resources of affected communities with a focus on protecting locally important assets. This integration of top down and bottom up approaches within a flexible risk based framework that pays attention to the dynamics of wildfire risks in situations of high dependency could greatly expand capacity, while reducing spatial dependency and incorporating local knowledge and priorities. Elements of this proposed approach exist in some federal jurisdictions including the EU, but rarely extend to local communities. Nevertheless, they could form a starting point for change. A 2020 report on wildfire risk in Europe highlights the current situation (Komac et al. 2020). It emphasizes that the evolving risk landscape is challenging. However, apart from a recommendation on the impacts of smoke on health and an increased emphasis on prevention, its recommendations do not depart significantly from current practice.

Author Contributions

JH and SHS conceived and designed the research question, contributed material and wrote the paper. TS, FG, and RM contributed materials.

Declaration of interests

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