Impacts of disasters on forests, in particular forest fires

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Executive summary

and services it provides. Pests can be native, with natural outbreaks occurring periodically; they can also be alien when introduced from outside of a given ecosystem. Both native and alien pests can become invasive when they extend beyond their known usual range, due for instance to climate change [7].

Windthrow: uprooting and steam breakage caused by wind, which often leads to űǊŜŜăΩ ŘŜļ·űKφ ¢Kλă common forest disturbance can range from a windfall affecting a small tree stand to an entire forest blown down during extreme weather events such as cyclones [8].

1.3. Fire-focused terms

Community-Based Fire Management (CBFiM): Fire management approach based on the strategy to include local communities in the proper application of land-use fires (managed beneficial fires for controlling weeds, reducing the impact of pests and diseases, generating income from non-timber forest products, creating forage and hunting, etc.), wildfire prevention, and in preparedness and suppression of wildfires [9].

Fire: product of a chemical reaction called combustion, an oxidation process triggered by the association of a fuel, a heat source, and oxygen, which releases energy, various gases (e.g., carbon dioxide, carbon monoxide, methane), organic matter, and water. In an ecological context, fire is often described as the opposite reaction to photosynthesis. This definition excludes the use of fire for domestic purposes [10].

Fire ecology: study of the interactions between fire (natural or anthropogenic) and the ecosystems in which they happen, and how these interactions evolve over time. The adaptation of natural organisms to the repeated passage of fire, from fire-resistance to fire-dependence, is a core topic of fire ecology [11].

Fire regime: main characteristics of fire activity for a given location, which can be reduced to the following essential parameters: seasonality, size, frequency, severity, type (e.g., ground or crown fire), cause (i.e., human vs natural). These characteristics are influenced by a number of natural and human factors (see pyrogeography) [12].

Prescribed burning: planned and controlled fire ignited in low fire danger conditions and used to meet management objectives, often for fuel load reduction and/or for ecological purposes. It is an umbrella term that is applied in different geographic and operational contexts, which can lead to confusion, in particular with traditional burning practices [13].

Pyrogeography:

increasingly seen as a sustainable and efficient way of maintaining ecosystem services and pyrodiversity while reducing wildfire risk [16].

Wildland-urban interface (WUI): umbrella term referring to areas where human-made infrastructures and assets (e.g., houses, water treatment plant, roads, farmland) are in contact or intermix with vegetated areas prone to wildfire [17].

1.4. Miscellaneous

Anthropocene: Unofficial yet popular term designating the current epoch, characterized by the general and measurable [illegible]-geo-chemical cycles caused by global and unsustainable human activity. The Anthropocene is now often illustrated through-143(thr)13((i)-3(l8eW* nQq0.00

impacts of hazards. Vulnerability is understood as the combination of exposure (to hazard), resistance [illegible] [25].

2. Introduction: Forests, societies, and disasters

2.1. The nourishing forests

2.1.1. Environmental importance of forests

Forests cover over [illegible] landmass, with an estimated count of nearly 3 trillion trees [26,27]; this number however is subject to debate, as forests definitions vary widely [28]. According to the Food and Agricultural Organization of the United Nations (FAO), about 45 % of forests are found under tropical climate, followed by the boreal, the temperate, and subtropical climate domains, together accounting for the largest reservoir of terrestrial biodiversity.

Forests, in their largest definition(s), provide a wide range of ecosystem services and benefits that are critical to the livelihood of communities, urban and rural, rich and poor, and from local to global scales [27,29]. These services are categorized as provisioning (e.g., timber, fuel wood, and other Non-Timber Forest Products), regulating (e.g., carbon storage, water availability and quality), cultural (e.g., landscape vista, sacred land), and supporting (e.g., soil formation, plant growth) (figure 1) [29ς31]. For instance, it is [illegible]

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fire on forests exist from multiple sources, those are incomplete or missing for other hydroclimatic events such as droughts, storms, and floods.

Fires

2.2.2. Biological origin

Biotic, or biological, disturbances are caused by living agents, either through direct exposure or as an indirect result of toxins and diseases that they may carry. Bark beetles, gypsy moths, fungi, viruses, and invasive exotic plants are examples of biological hazards threatening forest health throughout the world;

2.2.3. Man-made origin

Human-caused, or anthropogenic, forest disturbancesΣ άI·ǋŜ ƛyŘdzŎŜŘ Ŝყǘƛǋ Ŝfè ƻǋ ǇǋŜŘƻY ƛyI·yǘfè ōè ƘdzY I·y I·ŎǘƛØƛǘƛŜă I·yŘ ŎKƻƛŎŜăέ[5].

agricultural, ecological, or traditional purposes and spread to forests. Many recent extreme fire events [69] with extensive media coverage happened (partly) outside of forest ecosystems, in part due to the growing influence of climate change [70].

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When a certain type of fire activity happens to dominate over a substantial area and varies little over time, this fire activity becomes what is called a fire regime, a fundamental characteristic necessary to understand the location and the functioning of most vegetated landscapes of the world (figure 5, upper right) [74ς76]. Climate patterns (e.g., seasons), vegetation traits (e.g., conifers vs deciduous), and ignition patterns (e.g., human vs natural) interact to exert important control over fire regimes. For example, dry woodlands in the tropics often experience small-scale, low-severity fires set by human every 2 to 5 years to favour the growth of new grass more palatable for cattle; whereas in the northern boreal forest of Canada, large, high-severity fires are mostly lightning-caused, with a return interval often over a 100 years [77].

2.3.2. Fire in the Earth system

Fire has appeared on Earth nearly 400 million years ago and has since profoundly shaped ecosystems. The current global distribution, biodiversity, and services and benefits these ecosystems provide would be sensibly different in a fire-deprived world [11,77ς82]. Fire, as an ubiquitous process integrated within Earth System dynamics, is part of a subtle balance that influences climate, vegetation, land cover and land use, but is also influenced by them in return [83]. Some argue that over half the ǿƻNJƭŘΩǎ ǘŜNJNJŜǎǘNJƛŀƭ ecosystems need fire to stay healthy. Fire is thus an accelerator of evolution [82]. Over the 400 million hectares burned annually around the planet, forests account for less than 100 million hectares. Indeed, grasslands are by far the ecosystems that burn the most.

Figure 7: Illustration of the fire-productivity hypothesis; peak fire activity naturally happens in ecosystems where climate allows both vegetation to strive while experiencing dry seasons conducive to fire activity. (Source: https://media.springernature.com/original/springer-static/image/chp%3A10.1007%2F978-3-030-41192-3_1/MediaObjects/448910_1_En_1_Fig3_HTML.png from https://link.springer.com/chapter/10.1007/978-3-030-41192-3_1

Figure 8: Fires and climate feedback loop, with a focus on smoke.

3. Global status of forest fire activity

3.1. Recent significant events (2015-2020)

3.1.1. In Africa

The most significant events in Africa for the period 2015-2020 are as follow:

South Africa experienced wildfire disasters during the 2015 and 2017 fire seasons. In 2015, Western Cape region experienced human-caused 7,000-

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which explain spikes in area burned, especially in recent years [122,123]. After an early decrease at the start of the 20th century, area burned became stable until the 1970s and have been increasing since [113]. Fire frequency, after an increase during 1990-2010, has been decreasing. The average size per fire also has decreased, from nearly 20 hectares on average in 1980 to 7 hectares on average in 2019 for the southern part of Europe [87,116,121]. There is however an increasing trend countries. Recent area burned in Brazil was above long-term average (33.6 million in 2019, four times 2018) while fire frequency remains stable. Recent fire activity in several regions of South America seem to be linked to deforestation-related activities, and not climate change or natural fire regime. During the 20th century, fire activity decreased sharply in temperate South America, while area burned in Amazonia increased sharply from almost non-existent in the 1970s.

Fire frequency has generally decreased, yet individual fire size has increased. Regional increase in fire frequency is visible in southern Chile and at the southern fringe of the Amazon, while there is a decrease in fire frequency in the Amazon overall, as well as in northern South America and throughout Central America [87,116]. This fire activity is highly driven by deforestation for large-scale farming and open-burning in agricultural systems, although the Cerrado is a naturally fire-prone grassland region experiencing natural ignitions.

The fire season is getting longer in eastern and central South America, as well as at the extreme south of the continent (Tierra Del Fuego), while shortening in western South America as well as in several parts of central America. Overall, the frequency of long fire seasons has remained stable since the 1970s [88].

3.3. Predicted trends

3.3.1. Methodological background

Predicting trends in future fire activity is challenging, given the number of elements that control fire regimes. Some studies focus on predicting future fire weather only, which can be used to compute fire danger indices and extrapolate potential impacts on fire activity [129ς131]. Other studies adopt an integrated approach in which physical models of wildfire activity are ran as part of Earth System models, which include interactions and feedback loops among hundreds of variables, including vegetation change and human influence. The ultimate goal is to simulate future fire activity and understand how fire regime elements (e.g., season, cause, severity) might change;

3.3.8. In South

to an increased use of the landscape by human activities, this fuel build-up has favoured the occurrence of extreme fire events leading to disasters.

The introduction of exotic species can also seriously impact fuel load and fire behaviour. The continuing increase of planted forest cover since 1990 may be of concern from a wildfire hazard standpoint in several areas of the world, especially where non-native, fire-prone species are used for fast timber generation [158]. Eucalypt and conifer species in particular have been associated with several extreme wildfire events with disastrous consequences for surrounding communities, although the relationship between afforestation and fire activity is not unequivocal [140,159ς161]. In an era where planting trees to fight climate change has become a fashion, we need to think about the consequences for fire regimes; in some areas, planting more trees without a clear understanding of the consequences on fire activity might have more negative effects on the long run.

4.3. Climate change

Climate change, as threat multiplier, is becoming a leading driver of global fire activity [62]. Weather extremes are now on the rise, and droughts and heat waves τ as underlying factors of fire activity τ are happening more often and at a great magnitude. A warmer climate has been directly linked to higher fire danger [130,134,162]: fire seasons will become longer; drier and warmer conditions will make more vegetation available for fuel; increase in lightning activity will lead to more natural ignitions.

Predicted changes in vegetation assemblages and health, as well as improved spread capacities for invasive species, will lead to fire regime shifts [142]; actually, fire might even accelerate vegetation transition towards novel ecosystems [163]. European ecosystems are already suffering from these changes, leading to compounding problems such as droughts leading to further tree die-off and thus increased fire hazard [107,164]. However, studies suggest that long-term feedbacks might also lead to decreasing vegetation recovery and overall cover, leading to a decrease in hazard on the long run as fuel load diminishes [139]; the loss of ecosystems to the combined effect of climate change and fire is in itself a disaster.

Increasing length and severity of fire seasons create a particular concern for northern latitudes

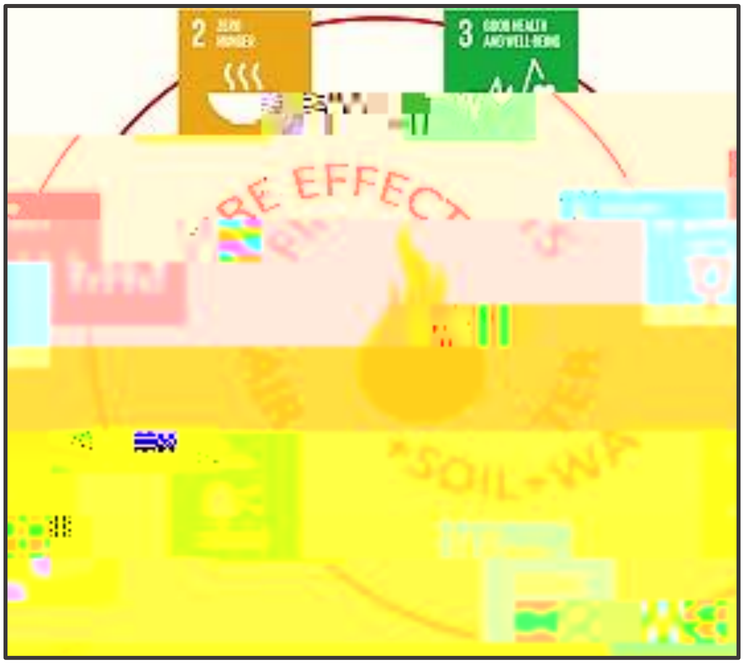

Figure 11: Direct and indirect impacts of forest fires can be detrimental to the completion of the Sustainable Development Goals (from [65]).

5.1. Ecosystem health

5.1.1. Impairment of ecosystem services

Fires need not to be extreme or to impact man-made infrastructures to have deleterious consequences. A wildfire might be limited to a distant, upstream watershed that supplies several communities downstream [169,170]; water pollution and decreased availability can be seen as detrimental, although not a disaster *per se*. That being said, extreme wildfire events have a destructive potential that can severely impact natural processes and functions, and thus the many ecosystem services and benefits that are supplied to communities [65,171,172].

There is now increased acknowledgement of risks to ecosystem services from atypical fire activity [78,173ς175]. For instance, forested watersheds provide an estiΥ l·űŜŘ τᵻ ϨŦ űKŜ ǿϨŇťŘŉă ǿ l·űŜŇ ădzLJLJťè, but severely damaged forests can compromise municipal water supplies, among other uses [176ς179]. Wildfires can have negative impacts on cultural and spiritual ecosystem services, such as archaeological values; with ongoing climate change, an increasing number of UNESCO World Heritage Sites are at risks from wildfires [180], such as the Mesa Verde National Park, in USA, with more than 4,500 archaeological sites. The sight of a burn landscape and the perception of a fire hazard can deter potential home buyers, which can be reflected in a dropping prices of properties on the housing market [181]. The closure of parks and other natural areas due to wildfire occurrence might drive tourists away and decrease important revenues for local people, along with associated losses of timber and other forest products. Finally, the impairment of air quality due to smoke is receiving an increased scrutiny from researchers and health services, as effects on health can be dramatic, on top of possible large effects on rainfall patterns [182,183].

5.1.2. Ecosystem recovery failure

The effect of climate change is already visible in many ecosystems in which fire plays an important natural role; this effect is predicted to amplify and change vegetation assemblages profoundly.

As increased temperatures and drier conditions will stress vegetation, fire might spread more easily through landscapes, including in locations that never or rarely experienced fire in recent history [184]. After the fire, different, sometimes more extreme, climate conditions might lead to difficulties for ecosystems to recover, even in fire-adapted ecosystems [185]. Even after recovery, generally more fire prone conditions will increase fire frequency in these ecosystems, shortening rotation and making it impossible for trees to reach maturity, leading to a slow decline in seed bank. Forest ecosystems might get younger, and eventually reach a tipping point and shift to a novel ecosystem [53,163,185,186].

These issues must be seen in the larger issue of forest health decline and potential failure to recover by natural means as climate change drives forests into respectively. Indirect fatalities can also happen during evacuation, as happened during the 2016 Fort McMurray fire in western Canada where two people died in a car accident.

The most widespread health issues relate to

All the issues listed above, and more, are expected to become more common and affect more people as WUIs keep growing and fire regimes keep changing [206].

Figure 12: Fire evacuees sift through a surplus of donated items in a parking lot in Chico, California. (Credit: Josh Edelson/AFP/Getty Images – retrieved from: https://www.theguardian.com/us-news/2018/nov/20/california-wildfire-refugees-

Given the diversity of social, economic, and environmental settings driving fire activity around the world, there is no one-size-fits-all, meaning that best management practices working in a given place might not work somewhere else. Ly̓ǘKλă ăŜy̓ăŜΣ ǘKŜ ǿϨfŘǿλŘŜ ǿλfŘŦλŜ ά[illegible] ŌI·y̓ōŜ ăŜŜy̓I·ă I· ǿλŎ[illegible]ŜŘ [illegible] τ one of these challenges that are so complex that they might remain conundrums forever. Given our globalized, high-tech, better informed, and rapidly changing world, wildfires can impact many facets of the system; however, there are immense possibilities for new, innovative, holistic and versatile approaches to existing and pressing fire management needs that are tailored to local issues. Importantly, working with communities, thinking fire as a solution in itself for restoring nature, and making sure fire management is integrated within larger strategies targeting nature restoration and climate change adaptation are keys to success.

On the bright side, we now know enough to make a change, so it not an issue of tools or knowledge, but of willingness to act. The following recommendations take place in the larger context of climate change reduction and adaptation efforts, whose importance and details go beyond the scope of this background paper.

7. Recommendations

In light of recent wildfire disasters and their likely increase if humanity fails to achieve the SDGs, several recommendations relative to policy interventions and other measures to be undertaken emerge for international organizations, national-to-local governments, the research community, the private sector, and NGOs, in order to reduce wildfire disaster risks, according to the priorities set by the Sendaï Framework for Disaster Risk Rq504 TQq0.00000912 0 612.59 T2(o)-5(t)9( )-12(aBT/F3 11.04 Tfq0.00000912 0 612.59 T2(

to a type of land management based on the controlled use of low-severity fire to reduce biomass and fulfil various land enhancement objectives, including wildfire hazard reduction. In Australia and the USA, aboriginal or Indigenous burning practices are increasingly advanced as a cost-effective way to reduce community and asset vulnerability. Essentially, these traditional burning practices can be ăǳϒϒl·ǊƛÎŜŘ ǿƛűK űKŜ ăl·èƛƴƎ άŦƛǊŜ ƛă l· ƎƧƧŘ ăŜǊØl·ƴűΣ ōǳű l· ōl·Ř ϒl·ăűŜǊέφ

All international organizations involved, even remotely, in fire-related disaster, TfTQq0.00000912 0 612 792 reW* n

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satellite offering all the necessary inputs for successful fire management. Such system will support emergency management by providing early warnings; this is the kind of information needed to then take advantage of machine-learning power towards the development of impact-based forecasting community empowerment, improved biodiversity and landscape health, reinvigorated cultural and social traditions. IFM builds on successful social interactions, on the integration of local knowledge and context, while securing financial support [236]. The success story of the Nature Conservancy in ½l·ϒōλl·Ωă Yl·ŦdzŜ bl·űλonal Park since 2011

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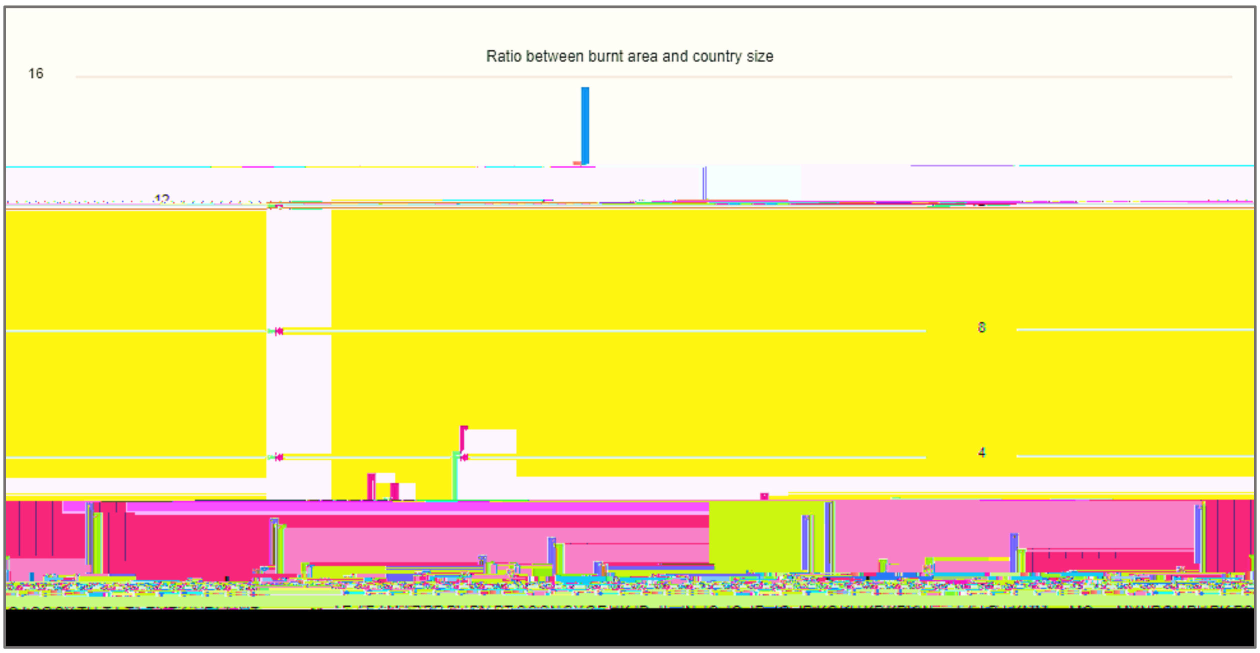
9.2.

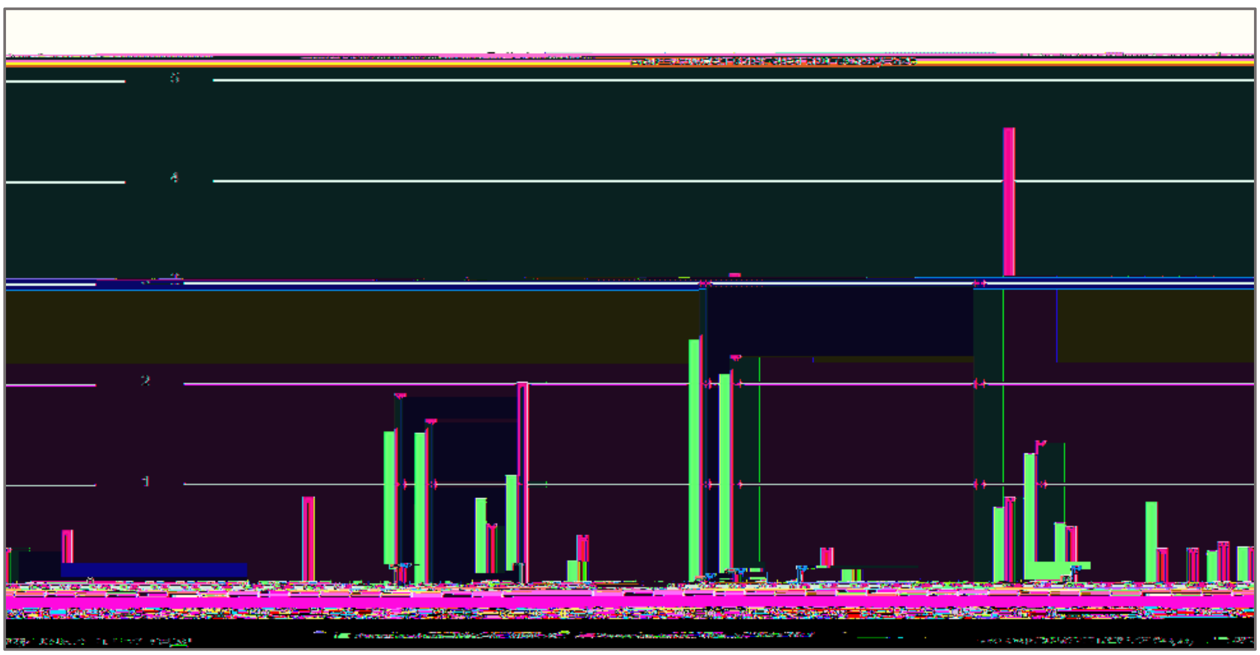
Africa

Asia and Middle East

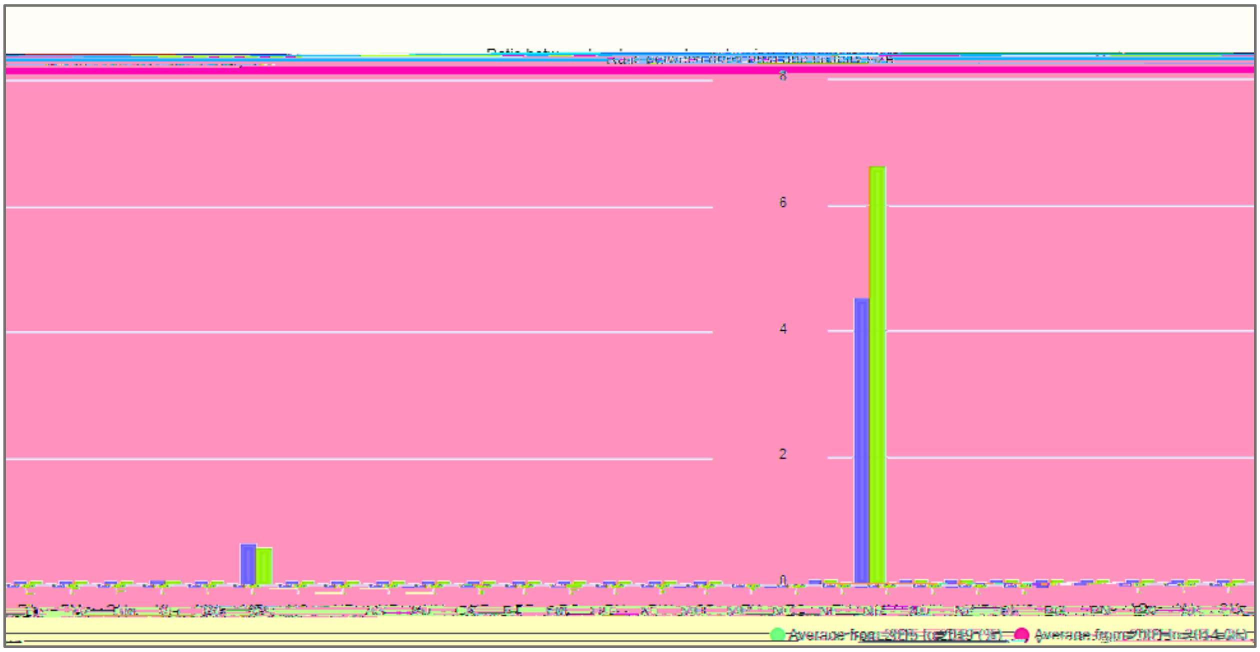


Europe

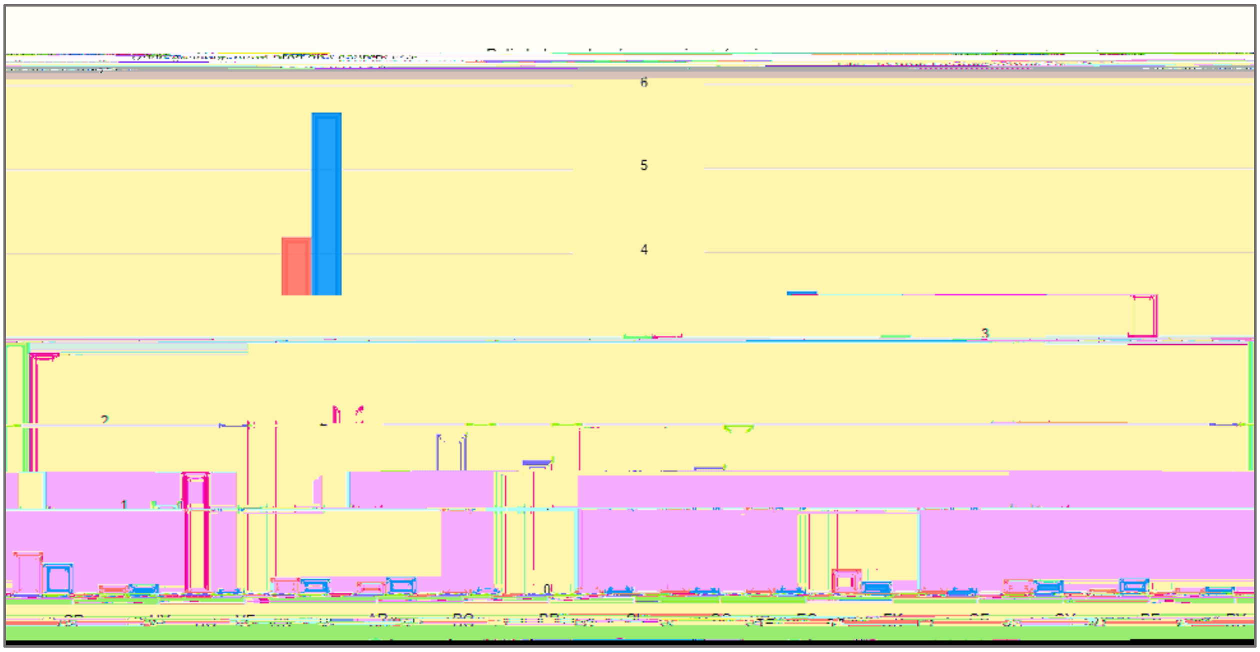
North and Central America



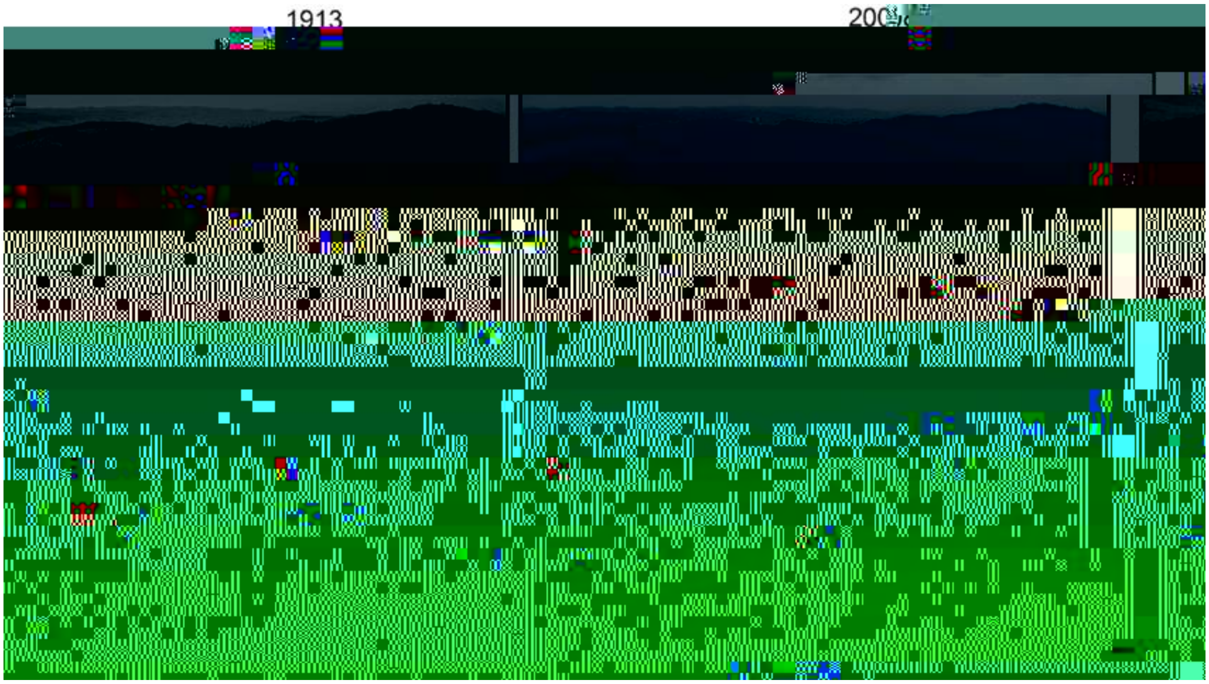
Oceania



South America

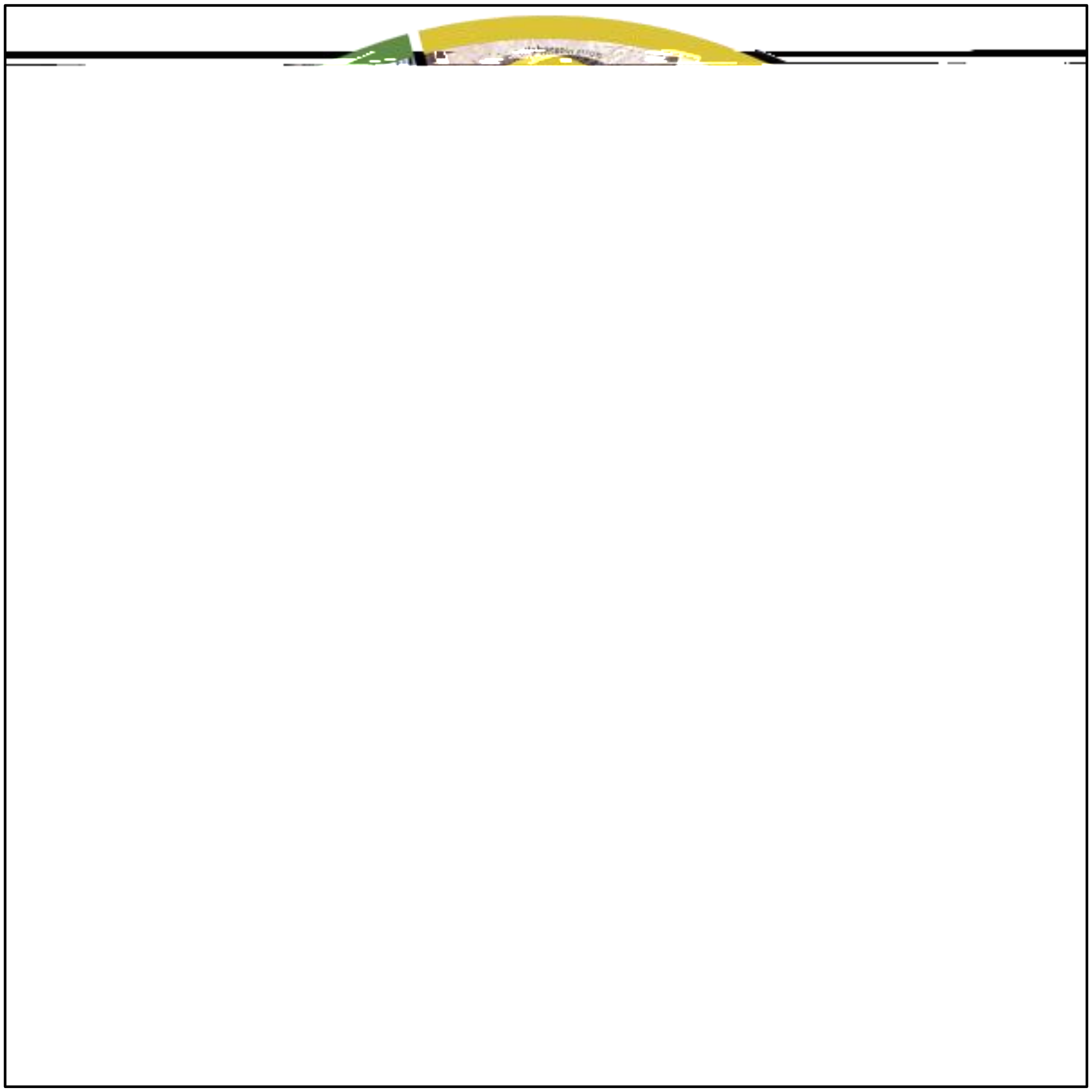


9.4. Examples of landscape transformation through fuel build-up from disappearance of traditional/historical burning practices



Example of forest cover changes due to fire exclusion in the Canadian Rocky Mountains. Source: [258] and the Mountain Legacy Project.

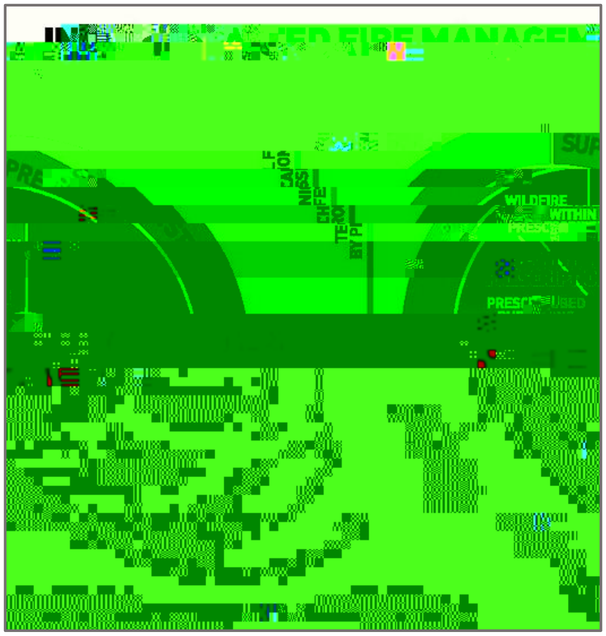
9.5. Integrated Fire Management (fire paradox)



10.

11. Figure 14: The Integrated Fire Manageemnt cycle. (Credit: Kishugu - https://kishugu.com/integrated-fire-management-services/?cn-reloaded=1)

In 2010, the European Fire Paradox project published its final report [259] with the following framework for integrated fire management. It differs substantially from the framework presented in the present report, but is offers a valuable approach to decision-making that embodies the core content of this background study.


WILDFIRE
WITHIN