Analysis of Bushfire Management in the Northern Territory

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List of Abbreviations

ABC	Australian Broadcasting Corporation
AUD	Australian Dollar
AusBIOSEC	Australian Biosecurity
AVHRR	Advanced Very High Resolution Radiometer
CAFS	Compressed Air Foam System
CEO	Chief Executive Officer
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organization
DENR	Department of Environment and Natural Resources
DEWHA	Department of the Environment, Water, Heritage, and the Arts
ERA	Emergency Response Areas
FAO	Food and Agriculture Organization
FMZ	Fire Management Zones
FPZ	Fire Protection Zones
GFDI	Grass Fire Danger Index
GFPA	Girls Fly Programme in Africa
IFM	Integrated Fire Management
JFSP	Joint Fire Science Program
MODIS	Moderate Resolution Imaging Spectroradiometer
NAFI	Northern Australian Fire Information
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organizations
NOAA	National Oceanic and Atmospheric Administration
NT	Northern Territory
RMIT	Royal Melbourne Institute of Technology
SOP	Standard Operating Procedure
TEMC	Tertiary Education Management Conference
USA	United States of America
USD	United States Dollar
USDA	United States Department of Agriculture

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Abstract

Bushfires are a major problem across many countries of the world that are dominated by forests, grasslands, and savanna woodlands. Each year, high-frequency and high-intensity bushfires result in severe economic and environmental losses, including loss of human lives and damage to property. The Northern Territory in Australia is one such region which is affected by several devastating bushfires on an annual basis. The objective of this research project is to establish and analyse the bushfire management strategies employed before and during the bushfire season in the Northern Territory, focusing on both their strengths and limitations. The research methodology adopted to address this objective was a systematic literature review and case study approach, and the bushfire management practices implemented during the bushfire seasons in the last 10 years were analysed. This analysis revealed several significant risk factors that led to catastrophic bushfires in the Northern Territory in 2020. It also highlighted the fact that prescribed burning was the most important bushfire management practice that was implemented in the region, and there was a need to implement more evidence-based strategies for controlling bushfires caused due to gamba grass and extreme climatic conditions. Based on this analysis, several recommendations were made regarding best practices to address the specific risk factors identified.

Chapter 1: Introduction

1.1 Background

A bushfire is a complicated climatic event that has catastrophic effects on a country's socio-economic environment (Dutta et al., 2016). Bushfires can be ignited by human activity or because of some natural phenomenon such as lightning. Either way, it causes a lot of damage to human life and property. The climate of Australia is slowly becoming hotter since the past few years, and the hot and dry wind provides the most suitable conditions for bushfires. The frequency of bushfires in Australia has increased by 40% since 2007. In 2007, there was an average of 3284 bushfires per week in Australia which ascended to 4595 by 2013 (Dutta et al., 2016). However, scientists reported that it is too early to link this increase in frequency with climate change (Salleh, 2016). From 1967 to 2013, major Australian bushfires caused more than 8,000 direct injuries and 433 direct deaths, resulting in an economic loss of almost 4.7 billion Australian dollars (Yu et al., 2020). Furthermore, in the last 30 years, 6519 homes have been destroyed due to these bushfires (Yu et al., 2020).

The significant impact of Australia's vulnerability to bushfire is evident, especially in terms of economic losses. Since 1980, almost 45 bushfires incidents have been reported in Australia (Commission et al., 2010). The five worst incidents were Ash Wednesday 1983, Canberra Bushfires 2003, Black Tuesday 2005, Black Saturday 2009, and Australian bushfire season 2019–20. Black Saturday was the most terrible incident as it took the lives of 173 people, destroyed 2029 homes, 61 businesses, and burned an area of almost 450,000 hectares including 70 parks and 3550 agricultural facilities (Commission et al., 2010). Ash Wednesday occurred in Victoria and South Australia and took the lives of 75 people, damaged approximately 2400 houses, and burned 418,000 hectares of land (Meteorology, 1983). Similarly, black Tuesday and Canberra bushfires resulted in 500 and 93 damaged houses and 160,000 and 77,964 hectares of burnt land respectively (Schapel, 2008). Direct damage to the property is listed below in Table 1.1. Recently the 2019–20 Australian bushfire season resulted in the burning of 18.6 million hectares of land, 5900

buildings, and 2800 homes. Furthermore, it is estimated that one billion animals of 113 species have died and some species have gone extinct (Baldwin & Ross, 2020).

Table 1.1: Major fire events since 1980

Date	**Event**	**Casualties**	**Direct Damage (Value in AUD at the time of the event)**	**Principal sources**
16-18 Feb 1983	Ash Wednesday (Victoria & SA)	75	400 million	(Criminology, 2014)
7 Feb 2009	Black Saturday Bushfires (Victoria)	173	3.2 billion	(Khan et al., 2019)
11-Jan-2005	Black Tuesday (SA)	9	100 million	(Schapel, 2008)
18-22 Jan 2003	2003 Canberra Bushfires	4	300 million	(Criminology, 2014)
1-Nov-2019 to 31-Jan-2020	2019-20 Australian Bushfire Season	34	-	(Baldwin & Ross, 2020)

Northern Territory has a fire-prone landscape with the number of fires events amounting to be greater than 80 annually (Russell et al., 2020). The fire management authority faces many challenges while dealing with bushfires. One of the main challenges is to ensure the safety of firefighters. Sometimes the fires are in inaccessible places with no escape routes so dealing with them increases the risk for the firefighters. A report by BBC News confirmed the death of 33 people including 4 firefighters in the bushfires till January 2020 (Australia fires: A visual guide to the bushfire crisis, 2020). Another major challenge is the difficulty of putting out the fire. Generally, 'water bombing' is used to put out the fire but this doesn't work in every situation. In regions of vast forestation, this method doesn't

work because the water disperses on the top of the trees and very less water reaches the burning logs at the lower level. There is a need for proper fire management mechanisms to be put in place in these regions to deal with the fire problem. Currently, the fire management in the northern territory is controlled and managed at the local level but this is not sufficient (Archibald, 2011).

1.2 Damage Caused due to Bushfires

Bushfires are normally considered catastrophic events due to their wide range, high intensity, and the fact that they cannot be easily extinguished by man (Leonard and Bowditch, 2003). This section details out the different types of impacts that are caused due to bushfires.

1.2.1 Economic Impacts

Damage caused by bushfires may be direct or indirect, where direct impacts include damage to infrastructure, disruption of electricity lines, and damage to agricultural land and buildings, and indirect impacts include contamination of potable water, disruption of transport, and disruption of tourism in the affected region. A bushfire can damage entire road networks, electricity and water distribution systems, and production of goods. Replacing these assets on a regional scale can turn out to be extremely expensive (Diaz, 2012). Destruction of trees that are an important source of timber and destruction of other raw material sources that are important for various industries can affect small-scale and large-scale production processes thereby impacting the economy of the region (Brunson and Tanaka, 2011). Additionally, some large bushfires may lead to the evacuation of people from a particular region causing the commercial industry to lose valuable customers. Apart from this, certain sectors such as event management may incur heavy losses due to cancellation of events such as weddings and conferences (Stephenson, 2010).

Bushfires are usually followed by an indefinite power cut during which time business owners cannot use equipment such as computers, printers, fax machines, internet services, air conditioners, refrigeration, and ventilation systems (Stephenson et al., 2013). Consequentially, production lines might need to temporarily halt and half-finished

products may need to be thrown away due to disruption of essential services. Some industries that are thus affected include printing industry, food industry, and chemical and refinery processing plants (Stephenson et al., 2013).

Not all bushfires are confined to the bushes, and in certain severe cases, fires may reach public and private properties, buildings, houses, and other infrastructure. In small towns where appropriate materials are not used for housing construction, a great deal of damage can be caused due to bushfires (Ulubasoglu et al., 2018). Important historic icons and symbols of cultural heritage have also been reported to be damaged in severe fires in the past. The repair and retreival of all these losses caused by bushfires may turn out to be extremely expensive for both the government as well as the people directly and indirectly affected by the bushfire (Ulubasoglu et al., 2018).

1.2.2 Social Impacts

These cover damages to the community, individual health both physical and mental, and cultural heritage symbols. As opposed to economic impacts, these damages are difficult to measure accurately and they are much harder to recover from because they may develop over a period of time and may require intense counseling for a longer duration. Communities not only include open-ended groups, but also people who are involved in managing the bushfire such as firefighters and other support persons (Stephenson, 2010). Bushfires probably have the most psychological impact on firefighters who have to witness extensive damage to property and human lives on a regular basis (Gordon, 2004). On the other hand, most people who are directly affected by the bushfire lose touch with the community for some time and concentrate on saving their families and belongings from the destruction caused by the bushfire. As a result, there is a loss of communication with people around them causing them to become detached from their communities. For a lot of people, it may be difficult to re-develop the bond they had earlier with people outside the affected region and this may end up affecting their health and well-being (Gangemi et al., 2003).

The second important part of the community after the bushfire survivors are the support staff and volunteers who are involved in managing the bushfire and promoting

relief activities. These people endure immense physical and psychological stress due to the nature of their work, and this stress is transferred to their immediate family members and close friends. In most cases, this stress is not appropriately addressed and it often culminates in emotional trauma or feelings of depression among these people (Regehr et al., 2000). Physical health is also deeply affected due to constant exposure to bushfire smoke, and the extent of physical damage depends on the health status of the individuals, duration of exposure, and nature of air pollutants. The chemical constituents that are left behind after a bushfire can enter a person's respiratory system leading to a sore throat, burning eyes, and runny nose. However, people suffering from asthma, respiratory conditions, and cardiovascular diseases may suffer more severe symptoms that may last for several days (DEWHA, 2005).

1.2.3 Environmental Impacts

Apart from human lives and infrastructure, the natural environment is probably the worst affected in any natural disaster. The negative environmental impacts caused due to bushfires affect the entire ecosystem and all its components such as water bodies, soil, animals, insects, aquatic life, and air (Stephenson, 2010). Soil acts as the basic structural component of an ecosystem for food chains to function smoothly and this component is highly affected after a bushfire. In the aftermath of a fire, there may be serious physical, chemical, and biological changes in the soil such as temperature alterations, nutrient depletion, changes in chemical constitution, and changes in soil hydrophobicity (Stephenson, 2010).

After soil, the next most affected aspect of the environment due to bushfires is water bodies such as lakes, rivers, and streams. As mentioned above, bushfires increase the hydrophobicity of the top layer of the soil leading to lower water retention, greater erosion, and impacts on vegetation (Lane et al., 2006). Air pollution is one of the worst impacts of bushfires due to the release of massive amounts of smoke comprising of ash, particulate matter, and volatile gases. The exact composition of the smoke may vary depending on fuel type being burnt, the amount of heat generated by the fire, and the speed and direction of the wind acting on the fire. Several gases present in smoke such as carbon dioxide, nitrogen

dioxide, and nitrogen oxide are greenhouse gases, and they can affect global temperatures leading to climate change (DEWHA, 2005).

Finally, bushfires have several deleterious and long-term effects on the flora and fauna of the regions exposed to smoke from the bushfire. In most bushfire-prone areas, the vegetation features several acquired characteristics to withstand the harmful effects of the bushfire; however, for plant species that are not adapted to tolerate smoke, they can be completely wiped out in the event of a large-scale fire (Stephenson, 2010). However, the effects of a bushfire are not all bad as some of the gases that are present in smoke such as phosphorus and nitrogen are essential for growth of plants. Despite that, the long-term effects of a bushfire on plant growth are mostly negative (Stephenson, 2010). Similarly, the effects of bushfire on fauna are equally devastating and can be both direct and indirect. Direct effects include burns, suffocation, and death due to direct contact with fire, flames and/or smoke. Indirect effects include forced migration, increased predation, change in habitat characteristics, and shortage of food and shelter (Whelan et al., 2002).

1.3 Research Problems

1.3.1 Bushfire Problems in Australia

In Australia, due to vast variations in climatic zones extending from the subtropical region to the southern temperate region, the nature and frequencies of bushfires too are dependent on these variations (Hirschberger, 2016). For instance, the tropical grasslands and savannahs in the northern region of Australia burn more easily and frequently as compared to the rest of Australia. In the southern region, the area that is prone to bushfires is small and the landscape is also highly fragmented. However, as the population density in the south is higher than in the north, the measurable damages caused to human life and property is much more in the south than in the north (Hirschberger, 2016). Figure 1.1 shows a map of Australia with areas that experienced bushfires in the year 2015. As evident from the map, the frequency of bushfires in the northern regions is much higher as compared to the southern regions, with central Australia being exempt from bushfires to a large extent.

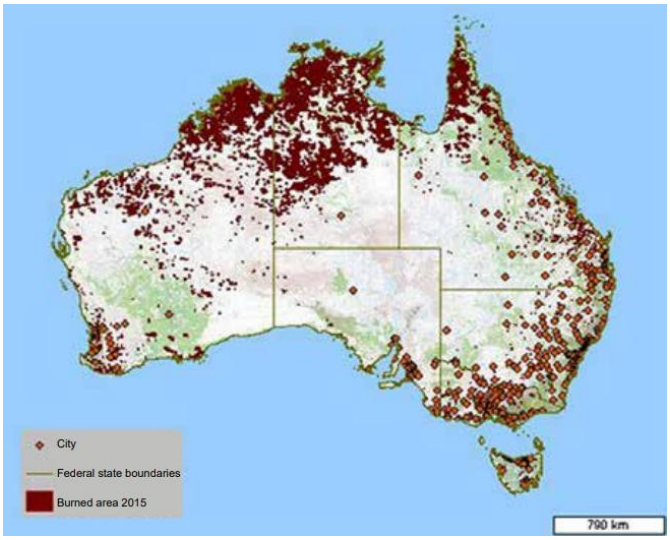

Figure 1.1: Map of Australia showing the areas exposed to bushfires in 2015 (Landgate, 2015)

Bushfires have plagued Australia since time immemorial resulting in hundreds of deaths and thousands of property damage incidents recorded. One of the oldest bushfires occurred in 1851 in Victoria and is known as the Black Thursday bushfire (Pounder, 1984). This bushfire incident damaged around almost a quarter of the entire land mass of Victoria resulting in 15 deaths and destruction of 1,300 buildings. Another devastating bushfire occurred in 1926 in Victoria, and is known as the Gippsland and Black Sunday bushfire (Pounder, 1984). This fire destroyed 400,000 hectares of land killing 60 people and destroying 1,000 buildings. This was followed by the Black Friday bushfire that occurred in Victoria in 1939 that burned through around 1,750,000 hectares of land mass. This incident killed 71 people, destroyed 1,300 buildings, and left around 3,000 people homeless (Pounder, 1984).

The 1957-1958 Blue Mountains bushfire occurred in New South Wales which destroyed 2,000,000 hectares of land killing 5 people and damaging 158 properties (Bowman, 1998). The next catastrophic bushfire occurred in 1961 in Western Australia which damaged 1,800,000 hectares of land and 160 buildings. Six years later, the Black Tuesday fires occurred in 1967 in Tasmania, killing 62 people and 86,450 livestock, destroying 4,000 buildings, and rendering around 7,000 people homeless (Bowman, 1998).

This was closely followed by the Daylesford Victoria bushfires in 1969 that killed 83 people and left around 800 people homeless. One of the worst bushfires in the history of Australia was the Ash Wednesday fires that occurred in 1983 in Victoria and South Australia (Bowman, 1998). This incident destroyed 2,500 buildings, killed 75 people, left another 9,000 people homeless, while burning through 210,000 hectares of land. This was followed by the Western Division fire in 1984-1985 in New South Wales that was ignited by lightning and led to over a hundred smaller fires in the region, burning around 3,500,000 hectares of land (Bowman, 1998).

The first fire of this century occurred in 2002/2003 after a long season of drought and affected New South Wales, Australian Capital Territory, Victoria, and Canberra. This incident resulted in a total financial loss of over 400 million AUD, death of 10 people and 12,000 cattle, and destruction of 1200 buildings (FAO, 2006). The next major bushfire occurred in 2005/2006 and it affected New South Wales, Victoria, South Australia, and Tasmania. It led to the destruction of dozens of houses, and death of two people and thousands of animals. This was followed by another major bushfire in 2006/2007 which affected Victoria leading to the destruction of 51 houses (Australian Emergency Management Knowledge Hub, 2017).

One of the worst fires in the history of Australia occurred in 2009 in Victoria, leading to the destruction of 450,000 hectares of land and 1800 houses, and death of 173 people. This fire did not happen all of a sudden and was the result of several phenomena such as low precipitation over a period of a few years leading to lowering of ground water level and drying up of soil, which eventually led to a major fire disaster (Reisinger et al., 2014). One of the major reasons for the extensive damage to human lives and property during this bushfire was that the people living in the subsequent areas were unaware of a fire risk and so, were unprepared. Reports have stated that over half the houses that were destroyed during this bushfire were not classified as “at risk” and the affected people were taken by surprise at the outbreak of the bushfire (Bushfire Cooperative Research Centre, 2009).

In the year 2013, the eastern region of New South Wales alone witnessed about 100 fires. All these outbreaks in total led to a financial loss of 183 million AUD that year

(Australian Emergency Management Knowledge Hub, 2016). In 2016, Tasmania witnessed a series of bushfire outbreaks following an extremely dry summer, spring, and winter that turned the normally humid environment of the region into a dry fire-prone environment. This series of around 300 fires was triggered by lightning which caused extensive damage and required large-scale fire management systems and firefighting planes to suppress the fires (Commonwealth of Australia, 2016).

1.3.2 Bushfire Problems in Northern Territory

Northern Territory or NT occupies a large portion of the northern and central regions of Australia and is bounded by Western Australia, South Australia, and Queensland. Despite being the 11th largest subdivision of a country in the world, its population is very low with just around 245,000 individuals living in the region (Population Australia, 2020). The NT has a monsoonal climate, which means that there is heavy rains for 6 months and the climate is very dry for the other 6 months. During the rainy season, the grasses and bushes of the region flourish and this landscape becomes extremely prone to fire during the dry season (Vanovac, 2018). Due to this type of climate, some of the most extensive and frequent fires occur in this region, and it is estimated that about half of the entire region is exposed to bushfires annually. A few of these fires are started deliberately to reduce the amount of available fuel in the region that can lead to bigger fires subsequently, and to manage the environment by controlling weeds and promoting regeneration (Vanovac, 2018). Other fires are started due to extremely dry climatic conditions, growth of flammable grasses, and presence of strong winds (Vanovac, 2018).

One of the worst fires in the history of Australia occurred in the Northern Territory in 1969/1970 in the region of Dry River and Victoria River. This fire burned around 45 million hectares of land area killing 23 people and 12,000 animals, and destroying 251 buildings (McFadden, 2020). The next major bushfire in this region occurred in 2002 which burned 38 million hectares of the land or 29% of the total land area of the NT region. This fire incident killed 7 people and destroyed 41 houses (McFadden, 2020). The initial fire was triggered by lightning following a period of extreme drought, and this subsequently led

to the outbreak of hundreds of smaller fires throughout the affected region (McFadden, 2020).

1.3.3 Bushfire Problems in the Global Context

The widespread occurrence of fires is estimated to have begun around 350 to 400 million years ago, and since then it has played a significant role in different aspects of our planet (He et al., 2015). Despite the fact that fires in the landscape, or wildfires as they are commonly known, play a very important role in sustaining the biodiversity and health of the ecosystem, currently its negative impacts on humans, animals, and the environment have come to light (Raftoyannis, 2014). As a result, the governments of various countries around the world are focused on developing and implementing strategies that can prevent wildfires or at least help regions recover from these incidents at a faster pace (Raftoyannis, 2014).

Fires are known to influence around 46% of the forest cover of the earth, and they are a common occurrence in regions of Taiga, savannahs of the Africa, dry forests in South Asia, coniferous forests in California, eucalyptus forests in Australia, areas of the Mediterranean region, and pine forests in the subtropical regions (Hirschberger, 2016). The frequency and intensity with which wildfires occur in these regions depend on several factors such as climatic conditions, type of vegetation available for burning, frequency with which lightning strikes in these regions, and biomass conditions. Figure 1.2 below gives a global perspective on the types and frequencies of wildfires that occur in different parts of the world (Hirschberger, 2016).

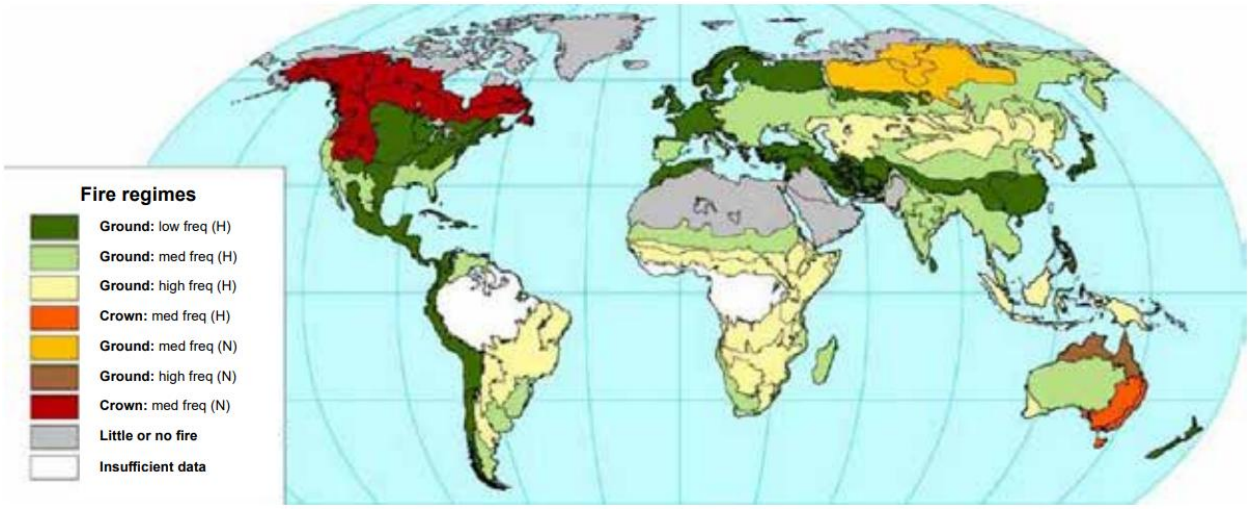

Figure 1.2: World map indicating the types and frequencies of fires occuring in different parts of the world. In the figure legend, 'H' stands for human-induced fires and 'N' stands for nature-induced fires (Hirschberger, 2016).

1.3.3.1 Fires in the Mediterranean Region

Species diversity is an important risk factor that makes the Mediterranean region vulnerable to wildfire outbreaks. As per recent estimates, only 17% of the original forest cover remains in this region due to exposure to several wildfires and its after-effects (Hirschberger, 2016). Small-scale fires have been common here since ancient times and they are considered an important tool of nature to manage natural resources and balance the ecosystem. However, due to global climatic changes, the numbers of wildfires have soared up in the past few decades in this region. Annually, the number of fires is around 50,000, which is estimated to affect around 700,000 to 1 million hectares of forest cover or 1.7% of the Mediterranean forest region (FAO, 2006).

Since the year 2000, the Mediterranean region has started witnessing a new type of wildfire, which is known as megafires. This has resulted from extreme climatic conditions that lead to the formation of firestorms that are so intense and uncontrollable, that they can only end when the fuel source runs out (Xanthopuolos, 2009). The damage caused due to megafires is immense and they lead to extreme loss of human lives as well as forest cover. For instance, a megafire in July of 2009 in the island of Sardinia accounted for a loss of 50% forest cover due to forest fires in the whole of Italy that year. Similarly, a megafire in

August of 2009 in the outskirts of Athens accounted for a 50% forest cover loss in Greece that year (Hirschberger, 2016).

1.3.3.2 Fires in the United States of America (USA)

In the USA, forests account for around 31% of the total land area and most intense wildfires that occur in the USA are confined to the western region of the country. The frequency of wildfires in the USA, as in all other regions of the world, can be seen to be increasing steadily with the passage of time (Hirschberger, 2016). From 1983 to 1989, around 1 million hectare of forest cover succumbed to wildfires annually. From 2000 to 2009, this number rose to 2.8 million hectares of forest cover annually. By 2006, around 4 million hectares of the total forest cover in USA had been damaged by wildfires. After 2010, it has been observed that although the number of wildfires is reducing annually, the amount of forest cover lost remains high indicating the occurrence of megafires (National Interagency Fire Centre, 2015). The year 2012 saw the largest fire in the history of New Mexico which destroyed 120,000 hectares of forest cover and the largest fire in the history of Oregon which destroyed 225,000 hectares of forest cover (Hirschberger, 2016).

The worst year for forest fires in the USA was 2015 which resulted in a loss of around 4.1 million hectares of forest cover in a total of 68,151 wildfire incidents. Forest fires in 2014 in the USA destroyed 1,953 buildings and caused two deaths in California (CalFire, 2015). The main reasons for this large number of wildfires in the USA include extremely high temperatures, drought, and increasing urbanization which has destroyed the natural landscape of the region. About 61% of all houses have been built in and around fire-prone regions thereby resulting in increased loss of human lives and infrastructure damage due to wildfires (USDA, 2014). The economic impacts of wildfires in the US are also immense amounting to 3.7 billion USD in 2012 and 3.4 billion USD in 2013 to manage the negative impacts of wildfires alone (USDA, 2014).

1.3.3.3 Fires in Germany

Germany is the second most wildfire-affected country in Europe after Poland, where the pine forests of Brandenburg are the most affected region. This is due to an extremely

dry climate, loose sandy soil that does not retain water, and around 70% of the area being covered by pine forests (Hirschberger, 2016). Additionally, climate changes in the last few years have led to the occurrence of long, dry, and hot summers which further exacerbate the risk of bushfires by encouraging the growth of flammable grasses and bushes. Examples of such plants include wavy hair grass and feather reed grass and these lead to an increased risk of bushfire occurrence in pine forests in the north eastern parts of Germany (Hirschberger, 2016).

1.4 Research Aim and Objectives

The main aim of this thesis is to evaluate the success of bushfire management in the Northern Territory, and to establish and address the gaps in bushfire management practices in the Northern Territory region.

The following are the research objectives:

- To provide an in-depth qualitative analysis of the risks associated with the outbreak of bushfires in the Northern Territory region of Australia
- To explore and evaluate the current bushfire management strategies that are employed in the Northern Territory in Australia through a case study analysis, and to consider what alternative strategies could have been employed to increase their effectiveness
- To identify the strengths and limitations of the current bushfire management strategies in the Australian context and propose possible improvements to these strategies so that they may become more effective in managing future bushfires in the region

1.5 Research Questions

- What management strategies are currently employed for bushfire management in the Northern Territory and how effective are they in controlling the frequency and intensity of bushfires in this region?

- How do the risks associated with the outbreak of bushfires in the Northern Territory region affect the effectiveness of bushfire management practices?
- What are the evidence-based bushfire management practices that could potentially reduce the impacts of bushfires in the Northern Territory?

1.6 Research Outline

This thesis is divided into 5 chapters. Chapter 1 provides a general introduction to bushfires, the range and extent of damages caused due to bushfires, the problems faced due to bushfire in the global and national context, and bushfire issues in the Northern Territory. It also throws light on what this thesis aims to achieve through its research questions and objectives. Chapter 2 provides an exhaustive literature review on best bushfire management strategies and practices around the world. It then goes on to compare these practices with the bushfire management strategies employed in the Northern Territory and analyse these strategies in light of the current scale of bushfire outbreaks. Chapter 3 provides the overall research framework and the research methodologies employed to inform this work. Chapter 4 provides an in-depth case study analysis and insights acquired from this analysis. It highlights the identified risk factors for bushfires in the Northern Territory along with the strengths and limitations of current bushfire management practices in the region. Chapter 5 provides recommendations and implications for future practice based on the case study analysis in chapter 4 and using examples from successful fire management practices around the world.

Chapter 2: Literature Review

2.1 Introduction

Bushfires are a natural part of several ecosystems around the world and are responsible for conservation of biodiversity and enrichment of the soil. However, in recent decades, the changes in climatic conditions and global temperatures have led to much larger and frequent wildfire outbreaks that have caused considerable damage to human lives and property. As a result, it has become imperative now more than ever to implement evidence-based and technologically sound fire management practices in order to prevent and/or manage the effects of wildfire outbreaks (Bushfire CRC, 2007).

The average annual bushfire management cost of Australia has been estimated to be 1.1 billion dollars since 2007 (ABR DRSC, 2017), with the Australian government spending 4 billion dollars for the management of the Black Saturday fires of 2009 (Teague et al., 2010). The theme that has emerged in recent times is the development of decision support tools or models that can mimic bushfires and help predict them long before they occur. In developing and implementing bushfire management strategies, it is important to acquire an in-depth understanding of how individual bushfires are ignited and carried across the region depending on specific vegetation and forest types. This understanding, combined with knowledge of impending seasonal conditions, can help predict bushfires weeks to months in advance, giving the local authorities and communities sufficient time to plan for the bushfire. Another important consideration in bushfire management is the appropriate allocation of financial resources for preventing and suppressing the bushfire, restoring damaged properties, and reviving affected forest regions (AFAC19, 2019).

According to the World Health Organization, around 180,000 people die due to direct or indirect effects of fires around the world annually (Mock et al., 2008). In Europe alone, around 3500 people die annually due to bushfires (Brushlinksy et al., 2016), and the same is true for the USA (Evarts, 2018). As per the International Association of Fire Safety Science (IAFSS), bushfires are a global problem that needs to be urgently addressed. It is an association of scientists, engineers, and fire safety personnel from around 40 countries that are involved in bushfire

management research (McNamee et al., 2018). One management practice that has appeared to be common especially among the indigenous tribes in different countries is the use of prescribed fires or cultural burning for promoting good agricultural practices as well as for preventing large wildfire outbreaks. Apart from this, there are several other fire management practices that are employed by different countries based on their specific risk factors and fire outbreak conditions (McNamee et al., 2019).

This chapter aims to review some of the best and most promising wildfire management strategies implemented in different countries across the world and analyse the reasons for their success. It also aims to analyse the current bushfire management practices in the Northern Territory region and compare them with those strategies followed in other countries. At the same time, this chapter will also evaluate the strengths and limitations of the bushfire management practices implemented in Northern Territory which will form the framework for subsequent analyses and proposals for new fire management approaches.

2.2 Bushfire Management Practices in the United States of America (USA)

Historically, Native Americans belonging to the tribes of Yurok and Karuk have practised the art of controlled burns or deliberate lighting of wildfires as a land and resource management technique. This practice has helped revitalize cultures, livelihoods and economies, and reduce the risk of extensive wildfire outbreaks. With the promotion of research in the area of successful wildfire management practices, this type of cultural burning practice by indigenous Americans has been dissuaded (Thompson et al., 2019). The tribals believe that the practice of lighting controlled fires provides ecological and social benefits while curbing the risk of sudden wildfire outbreaks. The people belonging to the tribes of Yurok and Karuk typically cut and burn stems of hazelnut shrubs leading to the subsequent growth of high quality stems that are unbranched, straight, and lack blemishes and insect bite marks. The tribals use these newly grown stems for making and selling fish traps and baby baskets. Therefore, the practice of cultural burning has been followed by the tribals for centuries for encouraging new plant growth and serving as a source of income for them (Busenberg, 2004).

Controlled burning in the form of prescribed fires also reduces the amount of fuel available for spontaneous wildfire outbreaks when the climate turns extremely dry. This not only reduces the number of wildfires, but also decreases the intensity of the fires that do break out resulting in decreased damage to human life, property, and natural landscapes (McCaffrey et al., 2013). However, these prescribed fires are not lighted randomly, but years of knowledge and experience have enabled the tribals to light prescribed fires to specific plants in specific regions at specific times and climatic conditions. For instance, the main objective of controlled burns for the tribals has been to increase food production and procure important minerals. These prescribed fires may also be lighted to destroy acorn-eating pests, improve nutritional value of plants, and promote positive changes in habitats of wild animals (McCaffrey et al., 2013).

Despite the positive consequences of prescribed fires by the indigenous people, the newly formed Forest Commission in 1905 started looking for scientific evidence or academic heritage on which to base these wildfire management practices (Mavsar et al., 2013). Most members of this commission were trained in Europe and thus, were of the opinion that fire was a social problem and cultural burning was a primitive practice that needed to be replaced with more evidence-based wildfire management strategies. The first professional forester in the USA, Bernard Fernow, hailed from Prussia, and he described cultural burning as a practice associated with loose morals and bad habits (Mavsar et al., 2013). Thus, people belonging to the newly instituted Forest Service began to seriously consider changing fire management practices and preventing indigenous people from lighting prescribed fires. This view became stronger in 1910 which witnessed a large fire outbreak that could not be controlled by the firefighters. Several events took place after this Big Burn which forced the then Forest Service Chief, Henry Graves, to consider firefighting as a scientific discipline and take effective evidence-based measures to control wildfires in the USA (Mavsar et al., 2013).

One of the first steps taken to fulfill this agenda was preventing cultural burning by warding off certain forest areas from lighting fires. They created demonstration forests to prove that prescribed fires were not a means of managing wildfires in the forests; rather they

exacerbated the problem of wildfires (Stephens et al., 2016). However, rather than fulfilling their objective, these demonstration forests served to prove to the Forest Service personnel that fire exclusion was not the right approach in controlling wildfires. They began undertaking research in possible fire management practices and started training men to fight fires effectively when they arise. They also started experimenting with fire danger rating systems that started serving as an administrative index for measuring performance of fire control and management practices (Stephens et al., 2016).

Eventually, fire management became more of a political issue and several Acts and Policies were passed regarding these practices. Some of the outstanding ones in the past few decades are Federal Wildland Fire Policy in 1995, establishment of the National Interagency Prescribed Fire Training Centre in 1998, and approval of funding for the Joint Fire Science Program (JFSP) which supported the use of prescribed fires as a wildfire management practice (Joint Fire Science Program, n.d.). The year 2000 saw the implementation of the National Fire Plan which mandated that fuel treatment in the form of prescribed burning would be the primary wildfire management strategy in the US (Balch et al., 2017). As a result, rather than focusing on how and when a fire outbreak will occur, this approach focuses on the source of fuel and its treatment such that it becomes resistant to large-scale fire outbreaks. Compared to other fire management practices, the approach of prescribed burning is easier to quantitate in terms of amount of area to be burned and the extent of fire to be ignited (Balch et al., 2017).

The 21st century is considered the era of the megafire where more extensive fire outbreaks occur which has resulted in extreme losses to human lives and property. However, there has been a concurrent increase in the research in fire management and several new avenues have opened up in the area of fire management such as remote sensing technologies, geographic information systems, atmospheric chemistry, and emissions studies. Despite this, the problem of wildfire outbreaks is still rampant and there is no ‘one solution fits all’ possibility in managing wildfires in the US (Field and Jensen, 2007).

2.3 Bushfire Management Practices in Germany

Germany experiences the most fires in the northern region due to a continental climate and poor soil characteristics. Additionally, there are large pine forests in this region that are extremely prone to fire outbreaks. Despite the problem of wildfire being present since centuries, agencies in Germany have only recently started considering the practice of prescribed burning as a fire management measure. In the 1970s, prescribed burning was first proposed as a pilot experiment to reduce the risk of wildfires in pine forests of Germany (Juarez-Orozco et al., 2017). Traditionally, fire has been viewed as a means of nature conservation, to protect and promote biodiversity, and to maintain the ecological characteristics of landscapes. However, land misuse practices such as grazing, mowing, and utilization of bio-fuels altered several vegetation types of natural landscapes thereby nullifying the effects of prescribed burning. This eventually led to a ban on prescribed burning by federal agencies in order to not harm the existing forest landscapes due to irresponsible practices (Rodriguez-Aseretto et al., 2013).

In 1997, a prescribed burning research program was initiated for managing the hedge and slope terrains in southwestern regions of Germany where viticulture was practiced to a large extent. The aim of this research program was to use prescribed burning as a means to protect grass cover that serves as a home to endangered species of plants and animals (Fernandes et al., 2013). This program, combined with several other initiatives undertaken in German institutions, has promoted several wildfire management practices in the areas of biogeochemistry and atmospheric chemistry. Several advanced sensor technologies and fire satellites have been developed to provide real-time spatio-temporal information for wildfire management purposes. Sensors for detecting high temperatures, and satellites for detecting bi-spectral infra-red radiations, and the autonomous early forest fire warning system have all been developed for informing wildfire management practices in Germany (Khabarov et al., 2014).

One of the problems in the wildfire management scenario in Germany is that insufficient data is available that can guide fire fighting and fire management practices in the country. This is because local authorities bear the responsibility of promoting fire investigation and

management practices in their areas rather than the national authorities and therefore, there is no consistency or format for collecting and maintaining data related to fire outbreaks in the country. Currently, the German Fire Protection Association (GFPA) is responsible for collecting and maintaining statistical data that can be used for analysis of fire outbreak incidents (Grabski, 2008).

In general, the fire management system of Germany is considered to be successful despite the complex network of decision-makers, all of whom have a say in the implementation of wildfire management practices (Wilgen et al., 2012). This is because the entire system is divided into several sub-systems that function as individual units to meet their specific objectives. Mathematically, these systems are considered non-linear chaotic systems; however, this German wildfire management system is an example that such chaotic systems can exist and function successfully (Wilgen et al., 2012).

Along with a strong system, they also have technologically advanced and sophisticated strategies and processes that make their fire management practices a huge success. The Research Centre of Fire Protection Technology at Karlsruhe has developed and tested several roof coverings against exposure to fire in the presence of strong winds (Jager and Schroder, 2016). It has also developed fixed sprinkler and water mist devices for extinguishing large-scale fires. Recently, they have been investigating the effects of water-gel substances and Compressed Air Foam Systems (CAFS). Another research institute in Germany has developed an aerosol extinguishing system that is used for generating water streams in the form of exhaust gas streams generated by a jet engine (Jager and Schroder, 2016). Yet another institute is involved in testing building materials for their fire resistance capabilities. An institute in Duisburg is involved in developing a technologically advanced automatic fire detection system that works by detecting characteristics such as smoke density, gases, dust, and heat. Another detection system that has been developed using the ultra-wide band radio technology can detect possible fire sources, persons trapped in fire-exposed areas, and the integrity of building materials (Jager and Schroder, 2016).

As mentioned earlier, despite the technological advancements in firefighting and fire management technologies in Germany, the absence of consistent and uniform statistical data related to fire outbreaks is a huge disadvantage as stakeholders in the country are unable to definitively determine the areas that are fire-prone and which need more funding for their wildfire management activities (Beard et al., 2003). Also, despite their technological advancements, they lack evaluation systems that can determine the rates of success of their fire management practices. Due to lack of data, they are unable to conduct an exhaustive risk management analysis that can guide future research in this area (Beard et al., 2003). Therefore, the country's current and future strategies for fire management involve engaging end users and individuals living in fire-prone areas for developing fire-safety techniques and practices. Also, given the number of fire safety and management research organizations in the country, the networking between these institutions need to be improved so that research is not repeated and specific objectives of fire management are met effectively (Beard et al., 2003).

2.4 Bushfire Management Practices in Brazil

Brazil is a country in South America that is extremely prone to fires to varying extents. The primary vegetation types of this region include rainforests, dry forests, semi-deciduous forests, savannahs, shrublands, and grasslands, all of which are subjected to both prescribed burning as well as burning due to natural triggers (Nepstad et al., 2001). Depending on the flammability and combustibility of these vegetation types, they burn to different extents and at different frequencies, and they are often classified as fire-sensitive and fire-dependent regions. In Brazil, tropical rainforests such as the Atlantic and Amazon forests burn more easily compared to other species (Nepstad et al., 2001). In contrast, savannahs and grasslands in the Cerrado region are more adapted to fires as this region has an alternate wet and dry climate and lightning-induced fires are common at an annual basis (Ramos-Neto and Pivello, 2000). The Pampas or the subtropical grasslands are located in the southern region of Brazil which, despite its humid climate, is extremely prone to fires (Nepstad et al., 2001).

Similar to indigenous groups in other parts of the world, the ancient tribes in Brazil too have traditionally used fire as a land management practice (Mistry et al., 2005). Following

European colonization, a large population of the indigenous groups was uprooted, which in turn caused a reduction in fire management activities in Brazilian forests. Prior to this colonization, the indigenous groups, especially the Kayapo tribes, created orchard patches by using fire to clear out the boundaries so that these patches would be protected from natural fire outbreaks. Also, a mosaic pattern of burning was used to increase biodiversity in the savannah regions (Hecht, 2009).

Since the last few decades, global increase in temperatures and the resulting drastic climatic changes have increased the flammability of the tropical forests of Amazon causing an increase in temperature, reduction in precipitation, and longer dry seasons. This has resulted in increase in risk of fire outbreaks and the gradual transition from tropical rainforest to seasonal forest (Eloy et al., 2018). Unlike Germany, the Brazilian government has always been heavily involved in fire prevention activities, and the Forest Fire Prevention and Control Policy ensures that several governmental and private institutions are involved in fire prevention and management activities (Fonseca-Morello et al., 2017). Some of the initiatives taken under this policy include fire detection satellites that provide real-time monitoring of fire outbreaks, use of data to geographically allocate fire brigades and surveillances, appropriate positioning of fire brigades, and dissemination of information regarding fire-free farming practices to small-holder farmers (Fonseca-Morello et al., 2017).

In the Cerrado region, the indigenous groups have traditionally used prescribed burning for cultivation of swidden across the landscape, harvesting of plants, and raising cattle. This was done in the form of a mosaic burning pattern in order to prevent the outbreak of larger fires and subsequent destruction of cultivable land (Russell-Smith et al., 2013). However, with the election of new members to fire management groups and institutions, a zero-fire policy was proposed in Cerrago which prohibited all forms of prescribed fire for the purposes of agriculture by indigenous groups of people. Over time, this policy led to the accumulation of fire-prone fuels and the outbreak of massive wildfires in Brazilian forests (Russell-Smith et al., 2013). Typically, these outbreaks occurred in the later half of the dry season and led to adverse effects on biodiversity, homogenisation of landscapes, animal mortality, damages to human

lives and property, and increased financial costs (Freeman et al., 2017). Considering the effects of the zero-fire policy on Brazilian ecosystems, several official and community fire management programs were initiated to manage large wildfire outbreaks (Van Wilgen, 2013). In certain protected areas of Cerrago, the combination of zero-fire policy and firebreaks has led to the occurrence of frequent megafires in the region (Pivello, 2011). In contrast, certain smaller protected areas have managed to completely eliminate fire by applying the zero-fire policy in their regions (Durigan and Ratter, 2016).

Within the last few years, the Brazilian government in collaboration with the German government has implemented an Integrated Fire Management (IFM) program in 2014, which is based on the savannah fire management experience of Australia. According to this program, patch mosaic burning techniques are used to create a mosaic pattern of burnt and unburntareas in order to prevent the rapid spread of large wildfires (Murphy et al., 2015). The objective of this program apart from fire management is to conserve biodiversity, protect the belongings of local communities, and to decrease the financial costs of large fire outbreaks (Freeman et al., 2017). This type of mosaic burning has emerged as an excellent fire management technique and is apt for the extent of species diversity in the Brazilian forest regions. Their focus is on fire management rather than fire prevention which enable them to achieve several objectives related to vegetation conservation and forestry. Therefore, mosaic burning does not follow a set routine in all protected areas of Brazil; rather, the nature of this type of burning varies according to the conservation status of the region, woody encroachment, and other local conditions (Schmidt et al., 2018).

2.5 Bushfire Management Practices in Africa

Similar to other countries, governmental organizations in different parts of Africa too had recognized and implemented fire management practices of local and tribal communities which included prescribed burning in strategic locations. However, this practice was challenged during the mid-20th century when several ecologists opposed the use of prescribed burning for fire management (Archibald, 2016). In 1984, an ecologist named Winston Trollope recommended that prescribed burning should be carried out only in wildlife areas, and other

fire management strategies should be devised to combat wildfires in residential and commercial locations (Archibald, 2016).

Following the policy changes in the 1980s, many new and different approaches replaced prescribed burning in several regions of Africa. The fires that were sparked by lightning were not subjected to any fire suppression method and were allowed to burn freely. However, all other fires were subjected to various prevention, suppression, and management strategies (Dube, 2013). Eventually, in 2002, point ignitions were introduced and these were used to start small fires in forest areas, woodlands, or grasslands whenever necessary. The fuel loads in various regions was accurately evaluated and this was used to determine the frequencies of implementing point ignitions, at the same time keeping in mind the necessity of available grazing land for cattle (Dube, 2013). This practice of starting point ignitions replaced the practice of block burning and it served in creating patchiness in the grasslands thereby prolonging the ignition season. The objective here was to light fires that most closely resembled the natural state of the forests by creating a mosaic pattern of ignition. As these fires had different times of origin, they succeeded in promoting biotic diversity in the areas in which they were lighted (Dube, 2013).

Another approach was the simulation of lightning-induced fires by considering factors such as fuel load, time since the last fire, and seasonal rainfall. This approach was used to create conditions similar to prescribed burning although in a more structured manner in order to bring about a strong framework in carrying out intentional burning (Wilgen et al., 2012). Yet another strategy developed during this time was the patch-mosaic burning system where the area of land subjected to fires per year was calculated by using values of the total number of fires and the grass fuel loads in a given year (Wilgen et al., 2012). Fires were sparked through the point ignition method taking into consideration fire weather and fuel loads, and these fires were allowed to burn out on their own. This strategy was implemented early in the dry season when the fires would be smaller and their danger levels would be lower. Apart from a fire management strategy, this approach is also used for conserving biodiversity and promoting heterogeneity in the landscape (Wilgen et al., 2012).

In the 1990s, the concept of adaptive fire management was introduced wherein various upper and lower thresholds were defined for different indicators in the ecosystem. These thresholds represented potential concern for starting a fire based on the observed fire patterns and fire weather conditions. For different threshold values, different fire management strategies were devised and they would be implemented based on the threshold level reached (Govender et al., 2006). The various factors that were taken into account for setting these threshold values were fire-return periods, desired fire intensities, seasonal fire distribution, size-class fire distribution, and the reason for their initiation, for instance, if they were natural or human-induced. If there were significant deviations from these threshold values, it would serve as an alarm system that would warn the relevant authorities of imbalance in the frequencies and/or intensities of the fires (Govender et al., 2006). This 'thresholds of potential concern' approach was proposed to replace the 'block burning' approach in an attempt to recreate natural fire-like conditions. However, eventually it became apparent that the thresholds approach was not very feasible and fire management experts went back to the block burning and patch-mosaic burning approaches (Govender et al., 2006).

2.6 Bushfire Management Practices in Australia

As the history of Australia has been marked with several devastating bushfires, there have emerged several fire management practices born out of research and observation of other countries around the world. Around 50,000 years back when humans colonized Australia, the forest landscapes underwent major changes being dominated by species of Eucalyptus and Acacia, and leading to major changes in the fire regimes of the region (Bowman, 2000). This was also the time that prescribed burning was introduced as part of Aboriginal fire practices, which further caused changes to bushfire seasons in various parts of Australia (Nicholson, 1981). Eventually, fires ignited on farms and pastures started moving towards high fuel loads due to human activities in the surrounding forest areas resulting in extremely large-scale wildfires (Ellis et al., 2004).

With the increase in frequency of wildfires in Australia, several state organizations were created to identify the risk factors for these fires and implement fire-safe practices to prevent

these devastating events in the future (Scherl, 2005). Also, as land managers became more aware of the risks of practicing prescribed burning on their farms, they started igniting low-intensity fires as practiced by the Aboriginal people in Australia. This type of planned fires based on technical and scientific research created a standard for effective land management practices that did not serve as a major bushfire threat (Scherl, 2005). After years of perfecting the technique of prescribed burning as a bushfire management practice, Australia has served as an example to countries like California who have recently started using prescribed burning to manage fires in their regions (Hesseln, 2000).

Apart from prescribed burning, there are several regulatory practices that are followed by different state governments in Australia which bring about structure to fire management practices in Australia. For instance, the Rural Fire Service requires every sub-division within its control to consult the state for land-use planning. This includes getting the approval from state authorities for construction materials, methods, and objectives of using the land for specific purposes (Stephens et al., 2009). The 1997 Rural Fire Act divided New South Wales into 142 fire municipalities, and the 2002 amendment further imposed getting the approval for housing construction from state authorities as well. This is a successful practice in Australia because it ensures that fire management begins from the planning and building process and that fire management standards are uniformly applied throughout Australia (Stephens et al., 2009).

Another important strength of Australian bushfire management practices is that it follows the 'Prepare, Stay and Defend, or Leave Early' approach wherein residents are advised to make their houses and properties fire-safe, stay on their properties and save it from the fire, or leave early enough when road travel is still safe. Some of the ways in which they are advised to defend their properties include fuel management, house protection, and ensuring availability of resources for fire management (Gill, 2005). Preparation of houses is an important part of fire management practices in Australia as well-built houses have been shown to provide a safe shelter for people during a bushfire event (Cohen, 2000). This is based on the fact that fire fronts usually pass quickly and well-constructed houses can protect its occupants from heat, smoke, and embers. The major damage to houses is usually done by embers and residents need

to be well-prepared to put out small fires caused by these embers so that their properties and lives remain protected (Blanchi and Leonard, 2008).

Victoria's 'Operation Fireguard' programme is an educational initiative undertaken by the state to make people aware of the bushfire risk and management practices. As part of this programme, training courses are conducted before the bushfire season every year and several articles are published in newspapers informing readers of the latest developments (CFA, 2007). All people in fire-prone regions are encouraged to prepare action plans where they can either choose to 'leave early' or 'stay and defend'. At this stage, residents and land-owners are also encouraged to think about their landscape, infrastructure, and equipment in terms of whether they can withstand the bushfires or not (CFA, 2007).

Australian financial practices for bushfire management are also noteworthy as around 17% of fire insurance premiums collected by private insurance companies are used for bushfire mitigation practices. This money is specifically used for rural fire management, fire management in populated communities, and for public education and awareness programmes (Henri, 2003).

2.7 Bushfire Management Practices in the Northern Territory

Since the last three centuries, prescribed burning has been at the heart of bushfire management in the Northern Territory region, until colonization by the Europeans disrupted these practices leading to the outbreak of several devastating fires during the annual bushfire seasons (Russel-Smith et al., 2018). The 1990s have witnessed the growth of several Indigenous Protected Areas (IPAs) and community ranger groups in an attempt to reinstate the age-old Aboriginal land management practices for fire management (Altman and Kerins, 2012). Gradually, the Indigenous population, scientists, funding agencies, and fire management authorities began bringing about a structure to prescribed burning based on current climatic and fuel conditions (Cooke, 2009). Some of the practices that have been adopted by fire management authorities in the Northern Territory region are discussed below.

2.7.1 Bushfires Management Act 2016

This Act was introduced in November 2016 and it provides a strong legislative framework for prevention, suppression, and management of bushfires in the Northern Territory region. It acts as a replacement of the old Bushfires Act (NT) that was active before the introduction of the new Act. As part of this Act, Bushfires NT provides the requisite support to local communities and property owners to co-ordinate regional fire management strategies (Eburn and Cary, 2017). It also provides support to firefighters, volunteers, and other people who are directly involved in fire management in order to ensure that they are well-provided for financially, physically, as well as mentally (Eburn and Cary, 2017).

Under this Act, the entire Northern Territory region is divided into 5 Fire Management Zones (FMZs) and several Emergency Response Areas (ERAs). The FMZs are further divided into Fire Protection Zones (FPZs) based on the available number of resources and sizes of the properties. A regional committee in each of the FMZs is responsible for implementing fire management plans in their specific areas while the Northern Territory Fire and Rescue Service is responsible for bushfire management in all the ERAs (Eburn and Cary, 2017).

2.7.1.1 Fire Bans

Fire ban periods are declared when the weather and vegetation conditions are extremely conducive for igniting a high-intensity fire. During such periods, bans are imposed on lighting fires on open lands in order to reduce any possibility of igniting a dangerous bushfire. These fire bans may be declared for a period of 24 hours, the only exemption being lighting fires for cooking purposes (Setterfield et al., 2013). People who do not observe fire ban periods may incur a maximum penalty of 500 units or imprisonment of up to 5 years. In case a fire on a property is already burning prior to the declaration of a fire ban period, the property owner is obliged to put it out immediately or notify an officer. Failure to do so may result in a maximum penalty of 200 units or imprisonment of up to 2 years (Setterfield et al., 2013).

2.7.1.2 Fire Breaks

All land owners in FPZs are required to install fire breaks around the perimeter of their property. Failure to do so may incur a maximum penalty of 20 units with an additional 2 units per day that the concerned person fails to establish a fire break (Price et al., 2007).

2.7.1.3 Fire Danger Warnings

According to the Act, Bushfires NT can give out fire danger warnings depending on the vegetation and weather conditions. These warnings can last anywhere between a few weeks to a few months and these warrant the implementation of extremely stringent fire management strategies in place in the declared fire danger zones (Anderson-Berry et al., 2018). During this period, fires cannot be lighted on open fields and great care should be taken that no such activity is performed where there is even a slight possibility of lighting an accidental fire. All these actions can incur heavy penalties or even imprisonment (Anderson-Berry et al., 2018).

2.7.1.4 Duties of Firefighters and Volunteers

Fire Control Officers, Fire Wardens, and all volunteers who have the necessary authorization are given the duty of assessing and managing fires, and taking all necessary steps for protecting a person or a property from destruction during a bushfire. These authorized personnel are given the permission to force entry into any property even if it means destroying locks or breaking down fences and gates (McLennan and Birch, 2005). In the event of a fire outbreak, they have the authority to stop traffic and restrict movement until such time that it is safe to travel through the area. They may establish fire breaks, destroy potential fuel sources, and undertake any other action that they think is necessary to protect people and properties from fire danger (McLennan and Birch, 2005).

2.7.2 Savanna Regional Bushfire Management Plan 2018

This plan has been formulated based on the Bushfires Management Act 2016 for management of bushfires within the Savanna Fire Management Zone. The purpose of this plan was to overcome the limitations in the implementation of the Bushfires Management Act in

specific areas, which may be extrapolated to other regions around the Northern Territory. One of the most important provisions of this plan is a strong communication strategy which ensures that all policy updates of fire management initiatives in the region are clearly communicated with all stakeholders (Russel-Smith and Yates, 2007). This is especially true for property owners who need to have complete access to good fire management practices and their specific roles and responsibilities under the Bushfires Management Act. One of the authoritative sources of information is the NAFI website which provides real-time information about fire weather conditions, fire danger zones, and general strategies for fire management (Russel-Smith and Yates, 2007).

Another provision of this plan is to promote collaboration with indigenous Australian communities as they have demonstrated outstanding knowledge of traditional fire management practices. Collaboration with other organizations such as the Volunteer Bushfire Brigades can also promote more effective fire management practices locally (Beringer et al., 2015). Partnerships between the property owners and governmental organizations are especially necessary for addressing the rapid infestation of the weed species, gamba grass, which is an extremely hazardous fuel source in the region. Other provisions of the plan include annual evaluations and reviews of fire management efforts, annual risk assessment, and cost benefit analysis of fire management practices (Beringer et al., 2015).

2.7.3 Bushfires NT Emergency Plan 2018

This emergency plan was prepared in response to catastrophic and deadly bushfires that are beyond the control of Bushfires NT and Volunteer Bushfire Brigades. Through this emergency plan, Bushfires NT focuses on involving local communities and property owners in preparation of a coordinated community response to bushfire suppression and management. This Territory Emergency Plan aims to provide the necessary resources and manpower to the key fire management organizations during a catastrophic event (Neale and Macdonald, 2019).

For emergency management of fires in the Northern Territory region, the controlling authority is Bushfires NT which is responsible for mounting an effective response to an emergency situation. It works closely with the Hazard Management Authority, using its

strategic advice and expertise in managing the disastrous fire situation in the Northern Territory region. Other key players under this emergency plan include Chief Executive Officer (CEO) of the Department of Environment and Natural Resources (DENR), Territory Controller, Territory Emergency Management Council (TEMC), and the Northern Territory Government (Neale and Macdonald, 2019). Some of the significant trigger points that can escalate a normal fire management strategy into an emergency management scenario include uncontrolled fires in rural areas, damage to domestic properties, extreme climatic conditions conducive for high intensity fires, fires proving to be a threat to human safety, fires moving into contaminated areas, and fires proving to be dangerous to large office buildings or public properties (Neale and Macdonald, 2019).

2.7.4 Fighting Fire with Fire: Prescribed Burning

The primary technique of fire management in the Northern Territory region is by means of prescribed burning. It is usually practiced early in the dry season when the temperatures are comparatively cooler and the chances of igniting an intense bushfire are lower. Apart from a fire management strategy, prescribed burning also helps in enhancing species diversity and lowering emissions of greenhouse gases (Radford et al., 2020). After years of trying different protocols of prescribed burning in the Northern Territory region, the government has come up with a savannah fire management method which combines all technical and legal obligations of fire management practices in the region (Radford et al., 2020).

Most of the mosaic burns are carried out around April and strategically selected areas are burned in controlled patches. This is immediately following the rainy season when the moisture content of the vegetation is just enough for it to burn but not so much that the resulting fires have the potential to turn catastrophic (Bhole, 2020). As a result, by cutting down the numbers of fires that occur in the Northern Territory region, the carbon emissions are lowered thereby having a beneficial effect on the climate as well. According to the NAFI website, the frequency of fires in Cape York Peninsula has decreased by 50% by implementing the prescribed burning method alone as seen in Figure 2.1 (Bhole, 2020).

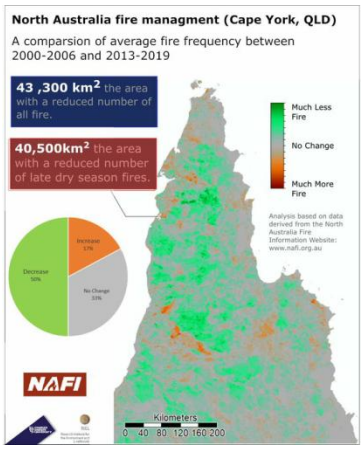

Figure 2.1: A fire frequency map signifying the reduction in the numbers of fires due to implementation of the prescribed burning method (Bhole, 2020)

2.7.5 Fire Danger Rating System

The fire danger rating system of the Northern Territory is quite unique as it uses the conditions of landscapes, vegetation, and weather to predict the fire danger levels in different areas (Grootemaat et al., 2019). Most forests in Northern Territory belong to the category of savanna woodlands or grasslands, or arid to semi-arid shrublands, and so depending on the indicative factors of the local grass species, the Grass Fire Danger Index (GFDI) is used to predict the fire danger levels (Grootemaat et al., 2019).

2.8 Conclusion

This chapter has highlighted the historically accepted and currently implemented bushfire management practices in different countries around the world, including the Northern Territory region. One of the fire management practices that is seen to be common to all regions around the globe is prescribed burning or intentional burning that has been practiced by indigenous communities since time immemorial. Apart from that, most fire-prone countries have developed sophisticated systems for risk assessment, risk management, monitoring and evaluation of fires, and fire management practices. All these strategies are implemented across different strata of the societies involving various key stakeholders in the process.

With this information, the subsequent chapters focus on the methodology, results, and analysis in accordance with the research hypotheses stated in chapter 1, and analyse the successes and failures of bushfire management practices implemented in the Northern Territory region in the last few years.

Chapter 3: Research Methodology

3.1 Introduction

Saunders et al. (2009) recommend a research onion for choosing a complete research methodology and framework to guide a research study as shown in Figure 3.1. The outermost layer of the research onion is the basic research philosophy that will guide the entire research methodology and analysis part of the research. Inner to this layer is the approach to theory development followed by the methodological choice being qualitative, quantitative, or mixed methodology. Inner to the methodology layer is the experimental strategy followed by the time horizon in which the study will take place. The innermost layer describes the specific procedures and techniques that will be used for data collection and analysis (Saunders et al., 2009).

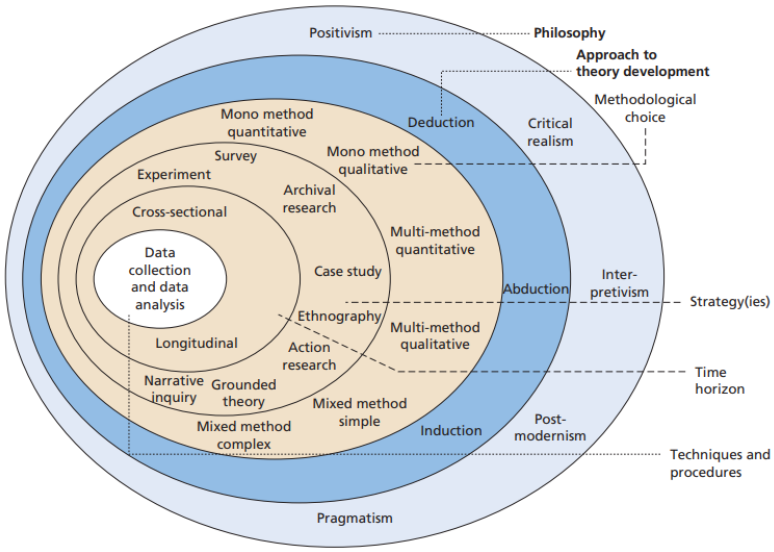

Figure 3.1: The research onion depicting various layers of a research methodology (Saunders et al., 2009)

This chapter provides a detailed description of the research frameworks and methodologies that have been employed to inform this work. Also, adequate explanation and justification of the individual components of the research methodological frameworks have

been provided. The limitations of the study have also been highlighted which in turn have affected the scope of the work and quality of the study.

3.2 Research Philosophy

A research philosophy is an approach that forms the foundation of the design, methodology, data collection, and analysis of a research study. It resonates with the researcher's beliefs and values regarding what s/he perceives to be truth and knowledge (Ryan, 2018). There are several major types of research philosophies that guide most of the research studies and these include post-positivism, interpretivism, critical theory, constructivism, participatory research, and pragmatism (Kaushik and Walsh, 2019). For the purpose of this research study, we have chosen pragmatism as our research philosophy.

Pragmatism is a research philosophy that believes in the plurality of methods, and the methodology selected as part of this philosophy is typically mixed methods. In this approach, the focus is on the research questions being investigated and the methods are selected based on the specific requirements of the research study. This approach rejects the traditional definitions of inquiry, reality, and knowledge and does not believe that a single methodological approach can answer the research questions being investigated. The word 'pragma' literally means 'action' and the research philosophy of pragmatism believes that actions are intrinsically linked to past experiences and lessons learned over time. People typically take actions keeping in mind the consequences of these actions, and the actual outcomes of these actions are used to inform future actions. Therefore, the focus in this research philosophy is actions and their consequences (Kaushik and Walsh, 2019).

3.2.1 Justification for Choosing Pragmatism as Research Philosophy

This thesis aims to investigate the current bushfire management strategies employed for fire management in the Northern Territory. This objective encompasses both the pillars of the pragmatist research philosophy, which are actions and consequences. In this study, actions are the practices and strategies employed for bushfire management in the Northern Territory

region, and consequences are the outcomes, whether positive or negative, of these bushfire management strategies. Therefore, in its most basic form, this research study aims to review the bushfire management strategies that are currently being employed in Northern Territory for preventing, managing, and recuperating from bushfires in the region. Furthermore, this study will provide a detailed explanation of the consequences of these bushfire management strategies and analyse if these practices are effective enough in preventing, managing, and controlling bushfires in the region. Based on this analysis, and drawing upon the bushfire management practices being employed in different parts of the world, recommendations will be made regarding the best possible means and approaches of managing bushfires in the Northern Territory region. As this methodology framework focuses on studying actions and their consequences in bushfire management, the research philosophy of pragmatism has been chosen for this research study.

3.3 Approach to Theory Development

The approach to theory development refers to the type of reasoning that is used to draw conclusions in a research study. There are three types of reasoning that are used to guide research, and they are deduction, induction, and abduction. These three are forms of inference that guide research methodologies in different fields. Deduction is a type of valid reasoning using which research hypotheses are tested and predictions are made by imagining the possible consequences if the proposed theories were correct. Thus, in deductive reasoning, a theory is proposed and based on the available information, the observations and consequences of the proposed theory are predicted. An important requirement for deductive reasoning is that the proposed theory must be sound and correct; only then can the predicted observations and its consequences be considered to be true (Montgomery, 2018).

In contrast, induction is a form of reasoning where generalizations are made and theories are proposed based on a set of observations. Data is first available for research and using this data, conclusions are drawn and research questions are answered. This may be done by identifying patterns in the data and proposing explanations based on available scientific

knowledge. In this case, conclusions drawn are not necessarily true and they are only inferences proposed by the researcher. In abductive reasoning, a researcher attempts to provide the best possible explanation for a set of observations or incidents. In this case, the observation or data available is true, but the inference and conclusion has an element of probability as it is based on the researcher's best judgement (Montgomery, 2018). For this study, the inductive reasoning method has been chosen for theory development.

3.3.1 Justification for Choosing Induction for Theory Development

This study aims to use available data and statistics from current bushfire management case studies in Northern Territory to form inferences on its quality, relevance, and effectiveness. In our case, we already have the data available which is the outcomes of bushfire management in the Northern Territory region. We aim to use this available information to identify the limitations of these bushfire management practices and conclude if they are effective enough or if they need to be altered to meet current demands. Using the inductive reasoning approach, we will be able to make generalizations and propose theories by analysing the available data. These theories may not necessarily be true; however, they will be backed by scientific evidence and will provide a framework for further analysing strengths, limitations, and failures in the current management system. These theories will further be used to propose alterations so that the current limitations of bushfire management practices can be overcome in the future.

3.4 Methodological Choice

Generally speaking, there are two major types of research methodologies which are qualitative and quantitative. Qualitative studies depend on descriptive, explanatory, and narrative data for making inferences and drawing conclusions. In contrast, quantitative studies use statistical data for proposing conclusions. Recently, a third mixed research methodology has started gaining popularity in the field of research, which is a combination of qualitative and quantitative methods. This is based on the premise that a lot of data that is available through theoretical or practical research has both statistical as well as descriptive elements, and so, a

mixed methodology is essential for providing a reliable analysis of such data (Powoh, 2016). Our study makes use of a mixed methods approach to analyse the available data pertaining to our research hypotheses.

In the mixed methods approach, both qualitative and quantitative data are used in the same study, so that a better understanding of the research problems, hypotheses, and the available information is possible. By incorporating both the qualitative and quantitative approach in a single study, it becomes possible to include all types of data in the study so that the inferences drawn are as complete and accurate as possible (Powoh, 2016).

3.4.1 Justification for Choosing Mixed Methods

A mixed methods approach is used in this study in order to acquire a complete and wholesome view of the available data. This approach enables insightful understanding on different levels of the research study. For instance, a qualitative approach may enable an in-depth understanding of the variables that formed the basis for subsequent statistical analyses. In our study, we have started with a qualitative approach in order to acquire familiarity with the bushfire management strategies in the Northern Territory region and to understand its limitations using descriptive and narrative texts. This has enabled a more accurate interpretation of the available data having acquired an in-depth understanding of the foundational premise of the research questions. Following this, quantitative data in the form of statistical reports were collected and analysed in order to build on our understanding of qualitative data.

Our primary reason for choosing mixed methodology for our research was to include all possible sources of information in our analysis, and to increase the validity and reliability of our study. Following either a qualitative or a quantitative approach would have resulted in loss of data that fell in the other category, and this would have affected the outcomes of our study. As the information pertaining to our research questions is extensive and is of a mixed type, a mixed methodology was suitable for providing a complete, reliable, and accurate analysis for our research.

3.5 Research Strategy

A research strategy provides a step-by-step guidance or plan of action using which the entire research study is built. There are several different types of research strategies and the choice of the strategy depends on the research questions, hypotheses, and research methodology. Some of the important strategies that are used to inform theoretical and practical research work include practical or field work, surveys and interviews, archival research, case study analysis, ethnographic analysis, action research, grounded theory, and narrative inquiry (Saunders et al., 2009). For our research, we have chosen case study analysis as our research strategy to answer our research questions.

Case study analysis is a research strategy that is used to provide an in-depth study and analysis of an individual, group, family, or organization. It may be used to analyse a single case or a series of related cases and is typically used for answering questions such as 'How?' and 'Why?'. It is used in instances when the events and/or practices are not reproducible and hence, practical or field work is not possible. It is also used when the number of stakeholders is diverse, and surveys and interviews provide a level of diversity in data that cannot be analysed conclusively. Although not widely used, the case study research strategy is very useful in analysing past events in order to inform and/or change the outcomes of future events (Fridlund, 1997).

3.5.1 Justification for Choosing Case Study as Research Strategy

The choice of case study analysis was most relevant considering the organizations and events that are the focus of the research questions of this study. The objective of this study is to analyse the strengths and weaknesses of the current bushfire management strategies employed in the Northern Territory region and to propose suitable alterations for better outcomes in the future. This was only possible through a case study approach where individual bushfire incidents that occurred in the Northern Territory over the last few years were analysed independently and thoroughly. The strategies used for bushfire management and the

qualitative and quantitative outcomes for each of these incidents was noted and analysed separately as well as collectively.

Practical experimentation was not possible as it is inconceivable to light a bushfire and test different management strategies. Questionnaires and face-to-face interviews were also not advisable as the experiences of victims as well as firefighters vary with the intensity and nature of occurrence of each bushfire. Archival research is irrelevant as the focus of this study is on current bushfire management practices so that future fire incidents can be better controlled. Ethnography is the study of different population groups with their specific cultures, customs, and habits, which is also irrelevant in our case. Action research involves elements of both action as well as research; however, our objective is to analyse actions that have already been taken in the past to inform the actions taken in the future. Grounded theory and narrative inquiry are both dependent on the acquisition of qualitative data; however, the sources and analysis of the data are not well-defined and are dependent on the datasets that are available to the researcher. Therefore, based on our research questions and hypotheses, the most relevant research strategy for informing this thesis is a case study approach where individual bushfire events that have occurred in the Northern Territory region over the past few years were analysedindepently, following which the primary analysis was pooled to make generalizations and draw conclusions regarding the strengths and weakness of the bushfire management practices that are employed in the region.

3.6 Time Horizon

There are two major types of data collection methods based on the timeline in which they are acquired, and these include cross-sectional methods and longitudinal methods. Cross-sectional methods refer to the analysis of a new sample set at a single point in time, whereas longitudinal methods refer to a long-term follow-up and analysis of the same sample set over an extended period of time. Cross-sectional studies work with several different sample sets and the implications of these studies are evident at a societal level. On the other hand, longitudinal studies follow the same sample set gathering data at different time points in the study and the

implications of these studies are observable at an individual level (Payne and Payne, 2004). In our research study, the cross-sectional research design has been selected for time horizon of data collection and analysis.

3.6.1 Justification for Choosing Cross-Sectional Research Design

Bushfire incidents in the Northern Territory region, that are the focus of this study, are individual events that occur in a single point in time. Analysis of a collection of such individual events calls for a cross-sectional approach as the repurcussions of these events are not continuous, rather they occur once and then the focus is shifted to another independent bushfire incident. Also, the outcome of a cross-sectional research design is applicable on a group level or societal level rather than an individual level. This point is relevant in our study as any changes brought about in bushfire management practices will benefit all people who live in bushfire-prone regions and who may potentially bear the consequences of future bushfire incidents in their vicinity. Therefore, among the two types of research designs based on time horizons, the one applicable in our study is the cross-sectional research design.

3.7 Data Collection and Analysis Techniques and Procedures

One of the major considerations for any study is the data collection methods, and for our study, we have used desk research for data acquisition. Desk research, as the name goes, involves collecting data from a desk as opposed to field research that is more practical by nature. Desk research involves collecting data from existing resources in order to study events of the past, and analyse their strengths and limitations (Omona, 2013). In our study, we aim to analyse bushfire incidents and the management strategies employed for them in the past, and therefore, it involves collecting data from existing sources. Field work, if undertaken, might involve face-to-face interviews with firefighters and victims of recent bushfires in the Northern Territory region. However, this approach might not be sufficient to answer the research questions, and a combination of desk research and field research would go beyond the scope of this study. Therefore, the sampling method chosen for this study is desk research.

The sources of data will include technical reports, government websites, journal articles, and news articles, ensuring the credibility and authenticity of the data obtained. All of this data will be acquired from the internet as this is a place where information is easily available and is most updated as compared to books and offline publications. As the data will be acquired from already published reports and articles, the data type used in this thesis is secondary data as opposed to primary data that is acquired first-hand through practical experimentation. As the internet is a place where information is abundant and several different data sources are available, the data that will be used to inform this thesis will be available in a large quantity and therefore, the content analysis will be rich in detail and more wholesome for making recommendations.

Apart from data collection, another important part of any research study is data analysis. There are several different methods available for data analysis such as qualitative analysis, quantitative analysis, text analysis, statistical analysis, diagnostic analysis, predictive analysis, prescriptive analysis, and thematic analysis. Keeping in mind our use of mixed methodology for this study and the possibility of extensive diveristy in data obtained, a mixture of predictive and prescriptive data analysis was employed for this study. Predictive analysis uses available data to identify patterns and trends, and predict future outcomes on the basis of past data. Traditionally, predictive data uses computer algorithms to identify patterns in the dataset; however, in our case, pattern identification was done without the use of computers. Prescriptive analysis involves data analysis followed by future recommendations and courses of actions based on the analysis. In our study, data obtained from various case studies was analysed to identify patterns, and this was further used to make recommendations for future practices.

3.8 Methods

In order to address the research objectives of this thesis, a systematic literature review was conducted using the internet and online databases such as Google Scholar and EBSCO Host, and different combinations of keywords such as fire, wildfire, bushfire, forest fire, risks,

prevention, management, and Northern Territory. A combination of journal articles and news reports were used to gather information pertaining to the research objectives. The selected sources were included in this study if they were dated between the years 2000 and 2020, and if they specifically discussed the bushfire management practices in the Northern Territory. Sources that spoke about bushfires in general, were dated before the year 2000, or that discussed bushfire management practices of Australia were excluded from the study. Apart from news reports and journal articles, reports from national websites and organizations such as Bushfire CRC, CSIRO, and AFAC were also included in the study provided they met the inclusion criteria.

For the case study analysis, an in-depth evaluation of the last 10 bushfire seasons, risks that led to these bushfires, damages caused, and management practices adopted was undertaken. The sources used for this analysis were news articles from authoritative news websites and reports from bushfire management organizations such as Bushfire CRC in the Northern Territory. From this analysis, the strengths and limitations of the bushfire management practices in the Northern Territory along with gaps in this area were identified.

3.9 Summary

In summary, a pragmatist research philosophy and framework was used for this study with an inductive reasoning approach for theory development. A mixed methodology and case study approach was used to analyse different case studies and acquire both qualitative and quantitative data for the study. The timeline in which the study was conducted was cross-sectional rather than longitudinal as it comprised of analysis of individual events in a single timepoint. Finally, the sampling method employed was desk research and the internet was used to collect secondary sources of data such as government reports, organizational websites, journal articles, and news articles. The data analysis method was a mixture of predictive analysis and prescriptive analysis applied on the data obtained from various relevant case studies of bushfire management in the Northern Territory region.

Chapter 4: Results and Data Analysis

4.1 Introduction

Using the internet and relevant online databases, various sources of information were accessed such as news reports, organizational reports, government websites, and review articles to acquire information about bushfires and their management strategies between the years 2011 and 2020. Only the past 10 years were chosen for the present analysis because we wanted to look at the current risk factors and bushfire management strategies, and evaluate their effects on bushfire management in the present climatic situation. We conducted an in-depth case study analysis for each of the years from 2011 to the current bushfire season of 2020, evaluating the risk factors, intensity and frequency of the bushfires, fire management strategies adopted, their strengths, and their limitations for each bushfire season. Based on this analysis, the risk factors that have been predisposing the Northern Territory region to bushfires currently have been described in detail. Additionally, the strengths and limitations of the bushfire management strategies that are implemented in the Northern Territory have also been presented in this chapter. Overall, the results of various bushfire management strategies that are adopted in response to heavy fuel loads and extreme climatic conditions along with their positive and negative consequences are covered in this chapter.

4.2 Risk Factors that make Northern Territory Susceptible to Bushfires

As per our initial case study analysis, there were several risk factors that came to light taking into consideration the bushfires that had occurred in the Northern Territory region over the last 10 years. Overall, there are 4 factors that determine the intensity of any given bushfire and they are ignition, fuel quantity, fuel dryness, and weather. Each of these factors is heavily dependent on several other factors such as meteorological conditions, spatiotemporal scales, and atmospheric circulation making it extremely difficult to predict the severity of bushfires in a given year (Harris and Lucas, 2019). Although conducive weather conditions is the most important risk factor for bushfires in the Northern Territory, there are also other factors such as

heavy fuel loads of gamba grass and firehawks that contribute to the spread of fire that can lead to devastating bushfires in the region. Each of these risk factors is elaborated below:

4.2.1 Gamba Grass

Gamba grass, or *Andropogongayanus*, came to the Northern Territory region from Africa in 1931 with the objective of increasing cattle production. It grows densely up to a height of 4 metres and is well-adapted to extremes of climatic conditions such as heavy rainfall and extended periods of drought, which enables it to out-compete the native grass species in the region (Neale, 2019). This has resulted in an increase in fuel loads from 6 to 30 tonnes per hectare providing a large amount of biomass for fires that burn with a greater intensity as compared to other fuel sources. Gamba grass also results in passive crown fires as compared to surface fires caused by other grass species, resulting in a vertical distribution of heat generated (Setterfield et al., 2013).

High intensity fires initiated by gamba grass as the fuel source can have devastating consequences for the biodiversity of Northern Territory, with the potential of changing woodlands to grasslands (Rossiter et al., 2003). An important concern of gamba grass is that it can grow equally in both fire-affected and unaffected areas. This means that areas that have been burnt by fires become inhabitable for native grass species, but gamba grass can proliferate at such sites thereby making it susceptible to bushfires in the upcoming season. As a result, woodlands that were once abundant with diverse species have now turned into frequently burnt lands that are habitable for only gamba grass species thereby affecting the biodiversity of the landscape. As gamba grass fires burn with much more intensity than normal fires, they are much harder to control and require more manpower and resources for their management (Setterfield et al., 2010).

4.2.2 Extreme Climatic Conditions

The climate of the Northern Territory region is monsoonal, which means that it has an alternate wet and dry season where it rains continuously for half the year and is dry for the other half. This region has an extensively grassy landscape which thrives during the wet season

and becomes fire-prone during the dry season. The combination of extremes in climatic conditions, large patches of flammable grasses, and strong winds lead to the initiation and spread of extensive wildfires. The northern region of Australia is shown to have the most frequent fires in the entire country, burning on average about half the land mass of Northern Territory. This pattern is also true for other wet-dry tropical savannah regions present in Asia, Africa, and South America where bushfires are a natural and necessary part of the landscape (Vanovac, 2018).

In Northern Territory, the peak bushfire season is during the dry period, typically during spring and winter. Hot dry winds blowing from central Australia towards the north increase the risk of spread of intense bushfires throughout the region. During the wet season, the quantities of twigs, barks, leaf litter, and grasses increase thereby increasing the amount of fuel loads in the region. During the subsequent dry period, the temperature is hot and the humidity in the atmosphere is low. This results in the drying out of vegetation making it more flammable in the presence of hot, dry, and windy conditions. The humidity percentage that generally poses an increased risk for bushfires is less than 20% in the atmosphere. Also, the presence of strong and gusty winds can fan the flames thereby causing it to spread faster and burn with more intensity (Harris and Lucas, 2019).

4.2.3 Firehawks

Firehawks are native Australian bird species that include black kites, whistling kites, and brown falcons. These birds are a particular concern in the bushfire scenario of the Northern Territory because they are known to carry flames in their beaks to push their prey from covered fields out into the open. They are also known as ‘arson raptors’ as they carry burning twigs or branches from a fire-affected area into another unaffected region thereby spreading fires across the landscape. For a long time, firehawks were not considered a serious threat to the spread of bushfires in the Northern Territory; however, since 2018, local ecologists and fire experts discovered what the Aboriginals already knew since centuries. Firehawks spread fires intentionally in order to scare out rodents and reptiles from a fire-affected area which become

their prey. They then repeat this process again and, over the years, this has become their source of survival (Bonta et al., 2017).

A notable feature about these firehawks is that they spread intentional fires when there are not a lot of fires burning in the landscape. In the traditional bushfire season, there are already a lot of insects and small animals available for them to feed on and so, they needn't spread fires to hunt for their prey. However, when the amount of food resources for these birds is scarce and they want to search for more prey, they use flaming sticks to spread fires across the landscape. Their range typically includes 2,400 by 1,000 kilometres for spread of bushfires. This is a particular concern when firefighters perform mitigation burns to avoid the possibility of intense bushfires in the upcoming season. Picking up burning sticks from a prescribed fire and dropping it in another dry land a few kilometres away can potentially lead to an intense bushfire in the field (Bonta et al., 2017).

4.2.4 Non-compliance / Arson

The year 2020 has seen catastrophic bushfires in the Northern Territory with heavy fire danger warnings and alerts throughout the region. With several million hectares already burnt in this year's bushfire season, there is a lot of reason for Bushfire NT and Bushfire CRC to suspect that some of these fires have been initiated deliberately. There is a lot of speculation that the current fires in Northern Territory are not a consequence of climate change; rather, they have been caused due to arson (Smith et al., 2019).

Specifically, arson refers to the deliberate lighting of fires by people with the objective of damaging houses, buildings, fields, and vehicles. Arson is a criminal offence undertaken to harm the belongings of another person without regards for its potential damages to other properties and the environment. On the other hand, non-compliance refers to negligence on the part of local citizens in the form of throwing away lit cigarettes or ignoring recommendations on fire-ban days. Although non-compliance is not a criminal offence, it plays a very important role in initiating extensive and uncontrollable bushfires in Northern Territory (Smith et al., 2019).

According to the National Centre for Research in Bushfire and Arson, the cause for at least 40% of all bushfires could not be assigned to any of the above mentioned risk factors; yet, less than 1% of the fires were considered proven cases of arson. The reason for this is that it is very difficult to detect cases of arson as all possible evidence is destroyed by the bushfire making it inaccessible for further investigations. A report prepared by the Australian Institute of Criminology in 2008 stated that around 13.3% of all bushfires were definite cases of arson. Around 35% of fires were considered accidental, and around 36.2% fell in the 'suspicious' category. If humans as risk factors can be removed from the equation, a large number of bushfires can be easily prevented in the Northern Territory region (Beale and Jones, 2010).

4.3 Case studies of Bushfire Management in Northern Territory

This section provides the results of our case study analysis of bushfire incidents, reported damages, and management efforts from the past 10 years. The results are presented in a chronological order starting from the year 2011 until the present bushfire season of 2020. A summary of the case study analysis is also presented in Table 4.1.

Year	Intensity of bushfire season	Risk factors	Strengths of fire management	Limitations of fire management
2011	One of the worst in the history of NT	Heavy rainfall after several years of drought, high fuel loads	Circulation of fire alerts and danger warnings, information given to people regarding safe practices	Less manpower due to inefficient retention of volunteers, lack of efficient strategies for prevention of bushfires
2012	Frequent bushfires every month	Extremely dry season, dry and gusty winds blowing from the southeast, high fuel loads especially of gamba grass	Prescribed burns	Inefficient prescribed burning leading to extensive fires every month

2013	High frequency and intensity of bushfires	Comparatively less rainfall, high humidity, isolated thunderstorms, extreme heat, rapid spread of gamba grass	Circulation of fire warnings, declaration of fire bans, MODIS instrument fitted with thermal sensors used for monitoring bushfires	Sudden heavy rainfall interfered with bushfire mitigation efforts and hindered accessibility
2014	More than a hundred incidents of bushfires, several hundred smaller isolated bushfires	Very heavy rainfall followed by dry and dusty season	Declaration of fire ban days, use of helicopters and water-bombing aircraft, installation of fire-breaks	Inaccessibility to remote areas where bushfires occurred, mitigation efforts insufficient to control large bushfires
2015	Worst since the bushfires of 2008	High rainfall, heavy growth of vegetation, occurrence of El Nino	Prescribed burning	Developed areas have insufficient space to light prescribed fires
2016	Bushfires of normal potential, very few and low intensity fires	Low rainfall, extreme hot temperatures, firehawks	Circulation of fire warnings, mitigation burns	-
2017	Scattered and controllable bushfires	High rainfall followed by intense dry period	Early lead in informing rural areas about fire dangers and implementing fire-safe practices, continous monitoring of hotspots	-
2018	High frequency and intensity of bushfires	Gamba grass, heavy rainfall	Mitigation burning, circulation of fire warnings and fire-safe	Limited resources for fighting bushfires ignited due to gamba

			practices among people	grass
2019	Extensively catastrophic bushfire season	Extreme weather conditions	Circulation of warnings and emergency alerts, installation of fire-breaks	Bushfire management strategies insufficient to control the intensity of the bushfires
2020	Heavy bushfire season predicted	Gamba grass, extreme dry period	Circulation of warnings and fire danger alerts, fire-breaks, hazard reduction burns	As per predictions, fire management strategies will not be able to control the intensity of bushfires

Table 4.1: An overview of all bushfire seasons, bushfire management strategies, and their strengths and limitations

4.3.1 Bushfire Season 2011

The year 2011 had one of the worst bushfire outbreaks in the history of Northern Territory. The occurrence of heavy rainfall during the wet season resulted in high fuel loads, and an intense and widespread bushfire season was predicted. According to Bushfire NT, the rains had occurred after several years of drought, thereby messing up the climate and vegetation status of the land. This was an indication that bushfire management over the last 10 years had not been very successful. Attracting and retaining volunteers was an issue which led to lesser manpower to manage the bushfires (Tlozek, 2011).

The Northern Territory Emergency Services had issued several fire alerts and danger warnings in response to predictions by Bushfire NT of a dangerous, rapid, and uncontrollable bushfire season. After several years, this was the first time that a catastrophic danger level had been declared in the Northern Territory region, and people were advised against using angle grinders, welders, or slashers that could potentially start a fire. Apart from this, it was evident that the bushfire-related organizations in Northern Territory were not prepared for a fire catastrophe and they were relying only on control of bushfires that were initiated accidently or due to weather conditions in the region (Brennan, 2011).

4.3.2 Bushfire Season 2012

The dry period in 2012 in Northern Territory was extremely dry, and the presence of dry and gusty winds blowing from the southeast resulted in the accumulation of high fuel loads and increase in fire susceptibility (Bureau of Meteorology, 2012). Long dry periods between consecutive periods of heavy rainfall especially favoured the growth of vegetation that served as easy fuel sources for bushfires. A particular concern was bushfires that were initiated by gamba grass especially due to the sudden drop in humidity following the wet season. Prescribed burns were also started early in the season by Bushfire NT with the aim of avoiding bushfire outbreaks in these regions in the future when the winds would be hotter and drier (Rawlinson, 2012). There were reports of extensive fires almost every month throughout the bushfire season resulting in a total number of 52 fire-ban days (Bureau of Meteorology, 2012).

4.3.3 Bushfire Season 2013

The prediction of bushfires in the year 2013 was high by the Bushfire CRC owing to comparatively lesser rainfall before the start of the bushfire season. North western parts of the Northern Territory region were estimated to be more susceptible to bushfire outbreaks due to rainfall in short intense bursts, high humidity, isolated thunderstorms, and a sunny weather. This order of climatic conditions allowed the growth of vegetation on vast expanses of land thereby increasing the susceptibility to bushfires. Another risk factor was the rapid spread of the weed, gamba grass, from the Darwin coast to Katherine in the interior leading to a trail of bushfires along this line (Bushfire CRC, 2013).

The summer season of 2013 was the hottest dry summer recorded for Northern Territory making it extremely vulnerable to an extensive bushfire season. Several fire warnings were issued by the Bureau of Meteorology along with several fire bans meted out by Bushfire NT. Due to high fuel loads and dry weather, the bushfire risk in 2013 was very high in Northern Territory (Bureau of Meteorology, 2013). Earlier in the bushfire season, a Moderate Resolution Imaging Spectroradiometer (MODIS) instrument fitted with thermal sensors on board an aqua satellite was flown over the susceptible regions to visualise the exact locations and intensities of existing bushfires. It was seen that strong winds were blowing the smoke towards the north

west of the Northern Territory, thereby covering the northern parts of Western Australia as well (NASA, 2013).

Despite below average rainfall during the rainy season, there was an unnatural increase in rainfall towards the end of the season which interfered with mitigation efforts undertaken to reduce the intensity of bushfires. Additionally, the late rainfall resulted in the development of several wetlands making access to the land for fire management efforts difficult. This was especially an issue in the Wadeye area, whereas in Douglas Daly, the presence of gamba grass made the area extremely prone to bushfires. Due to late rains, the curing of the plant species took place later and gamba grass is normally cured later than other plant species. Therefore, this unexpected climatic situation resulted in interference with fire management efforts as well as increased vulnerability to bushfires (Beef Central, 2013).

4.3.4 Bushfire Season 2014

The year 2014 saw huge bushfire losses marked by more than a hundred outbreaks of large bushfires and the imposition of twice the number of fire-ban days than usual. One of the major risk factors for bushfire outbreaks in 2014 was very heavy rainfall followed by an extremely dry and dusty season. In total, there were 127 major bushfires and several hundreds of smaller bushfires, with 14 of the major outbreaks occuring in the Katherine region alone. As compared to the average normal of 29 fire-ban days every year, the year 2014 witnessed a total of 60 fire-ban days. As per estimates, a little less than 50% of the entire land area of the Northern Territory was burnt in the bushfire season of 2014. There was some damage to commercial and domestic properties; however, overall the bushfire management was good as per reports (Curtain, 2014).

Due to the extremely dry weather conditions, the bushfire season had started earlier in 2014. According to post-bushfire estimates, more burning had occurred in the savannah woodlands as compared to the open grasslands. As these areas are located in remote regions of the Northern Territory, it is a little challenging to fight fires as well as to ignite controlled burns. The Bushfires NT organization makes use of helicopters and water bombing aircraft to control fires in these regions (Australian Geographic, 2014). In total, around 1,200 hectares of land was

burned in 2014, most of it concentrated in areas in and around Howard Springs and Humpty Doo. Other areas that were affected include Birrimba Station, Dungowan Station, Killarney Station, and Murranjai, along with around 400,000 hectares of pastoral country land. The primary management strategy that was used on these properties was installation of fire-breaks; however, it was insufficient to control the large bushfires that burnt through the areas (Brann, 2014).

4.3.5 Bushfire Season 2015

The bushfire season of the year 2015 is considered extremely bad after the bushfires of the year 2008. This year was marked by very high rainfall throughout the Northern Territory region resulting in the growth of copious amounts of flammable fuel sources. Despite the fact that the wet season ended comparatively early in the year 2015, a large amount of vegetation had grown and was available as fuel for bushfires (Bushfire and Natural Hazards CRC, 2015). This, coupled with the occurrence of El Nino, resulted in a prolonged bushfire season in 2015. The hot dry season continued until late November resulting in frequent bushfire outbreaks until that time. The Sturt Plateau had particularly experienced two cyclones earlier in the year, and this area experienced a larger number of bushfires as compared to the other regions. Additionally, this region is better developed than other areas and this makes practice of mitigation burning difficult due to lack of available space to light prescribed fires (Fitzgerald, 2015).

An important incident of the year 2015 was the mismanagement of a prescribed fire that led to a huge bushfire outbreak. A large quantity of weeds at the Ranger Uranium Mine posed a threat in the upcoming bushfire season and to avoid the possibility of a large bushfire outbreak, a controlled burn was performed in the region. Due to negligence of some important factors, this fire burned around 14,000 hectares of land at the Kakadu National Park affecting tourism and threatening several historic art sites (Price, 2015). The main reason proposed for this mismanaged controlled burn was lighting it too late in the dry season which made it difficult to be controlled. After the prescribed fire had ended, there was a change in the speed and direction of the wind, which re-ignited embers of the burn and carried it to other locations

where numerous individual bushfires were initiated. Subsequent investigations also revealed that permissions and/or approvals were not obtained before lighting of the prescribed fire, as a result of which expert opinions were not available for the controlled burn (Davidson, 2015).

4.3.6 Bushfire Season 2016

In 2016, the amount of rainfall in the Northern Territory was lower than average and the summer temperatures were extreme throughout the region. Most bushfire outbreaks in 2016 were of normal potential and could be easily managed by the traditional bushfire management practices in the region. There were some areas that were classified as below average fire potential due to the recent rains that had cured vegetation in several areas (Bushfire and Natural Hazards CRC, 2016). The estimation made by Bushfires NT also showed that the fire potential was reduced due to recent rains and minimisation of fuel loads. As a result, the bushfire season was dull with very few and very manageable fires. In total, 22 fire warnings were issued in Northern Territory throughout 2016. In addition, mitigation burns were also practiced widely further bringing down fuel loads in the region (Bushfires NT, 2016).

The bushfire season in 2016 brought to light another important risk factor of frequent bushfires in the Northern Territory region. An ornithologist found that Australian desert birds use fire as a means to hunt for their prey. They approach unsuspecting targets quietly and light fire to kill them before they can realise and escape. These fires at unplanned locations in the Northern Territory landscape may play a role in initiation of frequent bushfires in the region. The species of birds that use fire for hunting include brown falcons and black kites, and their grass fires help them prey on small birds, insects, and lizards that are scorched by the fire (Wilson, 2016).

4.3.7 Bushfire Season 2017

The year 2017 saw extreme weather conditions across the entire Northern Territory with a season of very high rainfall followed by an intense dry period. This type of weather is extremely conducive for initiation of bushfires. With the evaluation of the weather conditions and the risk of bushfires early in the year 2017, Bushfires NT took a lead in informing rural

communities about the dangers of the bushfire season and encouraged them to engage in fire-safe practices. Some of their recommendations included clearing of dried grass, fallen branches, and dead leaves to prevent the possibility of these fuel sources starting a fire. They also asked local farmers to remove species of grassy weeds from their properties and overhang structures of trees in their lands. The rural communities were also asked to install firebreaks around their properties and to keep the growth of vegetation within a height of 50 mm. This was in accordance with the Bushfires Management Act which states that the primary responsibility of bushfire management belongs to the property owners and failure to abide by the rules can result in fines or imprisonment (Department of Environment and Natural Resources, 2017).

Bushfires that did break out in scattered areas of the Northern Territory region were controlled immediately by Bushfires NT. Volunteers from the organization were continuously monitoring hotspots and curbing any fire spark so that it wouldn't turn into a full-blown fire. As a result, small fires that broke out in Tanami Desert and Gregory National Park were monitored and controlled effectively. They also continously monitored a fire in Sudan Station in Barkly that was active for about two to three weeks (La Canna, 2017).

4.3.8 Bushfire Season 2018

The bushfires in the year 2018 had been sparked by gamba grass, which led to the frequent occurrence of intense grassfires throughout the season. These fires were around 12 times more intense than fires sparked by other fuel sources and the economic impacts had increased by 30% within just a decade. An important concern during this bushfire season was that the resources for fighting fires caused due to gamba grass were limited. According to a news report, most proposed strategies are only in discussion stages and there are very few initiatives that have actually materialised (Smee, 2018).

Apart from gamba grass as the primary fuel source, the contribution of dry climate was minimal for the 2018 bushfire season as the Northern Territory region had experienced very high rainfall in 2018. The highest rainfall had occurred in parts of Kimberley along with several other regions in the Northern Territory (Braganza, 2019). As a result, the overall status of bushfires in Northern Territory in 2018 was considered mixed due to the heavy rainfall.

Therefore, although bushfires occurred sparked especially by gamba grass, they were of normal potential, and mitigation burning combined with circulation of SOPs among the local communities were sufficient to keep the bushfires under control (Bushfire and Natural Hazards CRC, 2018).

4.3.9 Bushfire Season 2019

The bushfires of the year 2019 have been described as 'apocalyptic' by one of the firefighters as they caused extensive catastrophic damage to various residents in the affected regions. Several hundreds of hectares of land that were either bushlands or orchards were completely destroyed in the bushfires. Concerned agencies had made use of several 'Watch and Act' warnings and emergency alerts to warn local communities about the impending bushfires. The local residents were also asked to implement a 4-metre fire break around their properties and to ensure that no flammable items were used during the danger period (Garrick, 2019). According to the Bureau of Meteorology, the bushfire season in 2019 was longer than usual with extreme and severe fire weather conditions that lasted for prolonged periods of time (Wahlquist, 2019). The latest government reports estimate the loss of land to be around 6.8 million hectares along with 5 houses that were destroyed in the bushfires (Siddeek, 2020).

4.3.10 Current Bushfire Season 2020

In the year 2020, an early start to the bushfire season has been warned by experts since June. This is because the extreme dry season has led to rapid drying of the vegetation leading to the initiation of 16 fires in the region. One of the major problems predicted for this early bushfire season is the presence of gamba grass in the tropical savannah regions, which has higher flammability as compared to other plant species. Bushfires NT is taking a lead in monitoring and warning local communities of the threat of bushfires this year. According to this organization, more than 50% of the bushfires this year have been initiated by gamba grass. These types of fires are characterised by more intense and fast-moving fires where embers move ahead of the fire front. Another risk factor is the occurrence of two dry-wet seasons followed by insufficient rain, which has led to extreme drying of the vegetation. As per Bushfires NT, 90% of fuel source in the region is already cured (Lemke, 2020).

One of the control measures adopted by Bushfires NT for controlling this year's bushfires is fire breaks and mitigation burns or hazard reduction burns in different fire-prone regions throughout the Northern Territory. However, the organization warns that efforts taken to control bushfires at this point in time might not be enough (Lemke, 2020). The organization has also issued fire danger warnings, fire bans, and closing of public places in fire-prone areas (Xinhua, 2020). The Bureau of Meteorology has also warned that this year's bushfires may be the worst since the Northern Territory bushfires of 2015. Total fire ban days have been declared for areas in Darwin, Daly South, Carpentaria West, and Gregory. Residents have been asked to avoid keeping any flammable items in their gardens or balconies that can easily catch fire (Gibson and Hynes, 2020).

4.4 Strengths of Bushfire Management Strategies in Northern Territory

This section details out the strengths of the current bushfire management strategies in the Northern Territory region based on the above case study analysis.

4.4.1 Individual Efforts

One of the most important strategies for bushfire management in Northern Territory is involving landowners in the fire management process. As evident from the above case study analysis, Bushfire NT constantly urges property owners to install fire breaks around their properties and not engage in any activity that could potentially lead to the initiation of extensive bushfires. The idea is to manage bushfires at an individual level so that each person becomes a responsible citizen by playing a role in the fire management strategies in the Northern Territory region. It encourages communication and co-operation within the community, and makes use of individual capacities to take self-protective measures for successful fire management in their communities. As their activities are controlled by the Bushfires Management Act, they have the liberty to make use of controlled practices for their land management objectives, at the same time ensuring that these are safe for themselves and the properties in their vicinity.

4.4.2 Prescribed Burning

Based on the above case studies, the most widely used bushfire management strategy on a large scale is prescribed burning or controlled burning. It is a means of fuel hazard reduction and is considered a cost-effective method of controlling bushfires over large areas of land. The objective of prescribed burning is to limit the surface area of fuels to about 8 to 15 tonnes per hectare of land (Cheney, 1996). It also reduces the height of the fuel sources and eliminates the fibrous barks of trees, which is a huge contributor to the spread of bushfires across forest lands. This approach cannot stop bushfires from igniting; rather, it is used to limit the fuel availability in the region, which in turn limits fire growth, height and intensity of the flames, and rate at which the fire spreads. According to a report by Esplin et al. (2003), prescribed burning should be increased in the Northern Territory region in a graded manner so that it can reduce and/or eliminate fuel sources for better fire management in the region. Studies have shown that increase in prescribed burns throughout the region can help combat extreme climatic conditions and the subsequent risk of intense fires (Environment and Natural Resources Committee, 2007).

4.4.3 Fire Suppression and Management Agencies

Throughout the Northern Territory region, there are different agencies who are assigned responsibilities for different land areas. Therefore, depending on the land area where a bushfire has been initiated, the relevant agency springs to action by means of ground crews and water-bombing aircraft. This is one of the important strengths of bushfire management in the Northern Territory as it is not possible for a single agency or a small group of organizations to cover the entire land area monitoring and suppressing bushfires. Also, the initial bushfire management response is mounted using local resources, following which resources from neighboring districts are requested for more effective fire management in the affected areas.

4.4.4 Use of Aircraft for Fire Suppression

Water-bombing aircraft has been deployed recently and provides a definite edge over ground fire suppression resources. Some of its key advantages include greater field of

observation, increased accessibility, and increased speed in reaching the location of the fire. This is especially important when the location of the bushfire is in a remote area and its accessibility via the ground is restricted. Water-bombing aircraft can reach remote locations very fast and begin suppression operations within a short period of time. It can also slow or halt the spread of the fire in adjacent areas until ground crews arrive and mount a high-intensity suppression response to the fire.

4.5 Limitations of Bushfire Management Strategies in Northern Territory

4.5.1 Limitations of Prescribed Burning

Despite being a fruitful strategy for bushfire management in the Northern Territory, prescribed burning doesn't work when the climatic conditions are extreme and the risk of fire danger is very high. Therefore, extremely dry and hot weather overpowers the success of controlled burns as well as the efforts of Bushfire NT's firefighters and volunteers. The weight of the fuel source has a great impact on the effectiveness of bushfire management strategies in the Northern Territory region. For instance, the adopted bushfire management practices are less effective for heavier fuels as compared to lighter fuels. This is the reason that bushfires are better controlled in mildly hot and dry weather giving firefighters an opportunity to suppress fires before conditions become worse during the traditional bushfire season. When fuel sources are heavy or the fuel loads are very high, fuel reduction burning can become problematic and there is always the risk of igniting a large uncontrollable fire. In such a situation, supression crews are not really prepared for controlling these types of fires thereby increasing the damage caused to human lives and properties. Another limitation to using prescribed fires is that there is always a residual risk of the initiation of an intense fire; therefore, in certain instances, it can end up doing more harm than good in fire-prone areas.

As per a report by Fernandes and Botelho (2003), prescribed burning is most suitable for heterogeneous landscapes and areas where variation in climatic conditions is low. Based on our case study analysis, in most years, the climatic conditions are quite extreme making prescribed burning an ineffective strategy for controlling intense fires in the region. Cary et al. (2009)

showed that weather management and ignition management were two important components of a successful prescribed burning strategy, and the strategic location of prescribed fires may be extremely significant in fire management. Some of the negative impacts of prescribed fires include potential loss of biodiversity, impacts on highly erodible soils, and negative health impacts due to smoke from prescribed fires. Therefore, especially in the Northern Territory region, it is essential to implement another strategy either alone or in combination with prescribed burning in response to extreme variations in the climatic conditions.

4.5.2 Limitations of Early Bushfire Management Efforts

The success of early bushfire management efforts is highly dependent on four factors – time of mounting the initial response, climatic conditions, fuel hazard, and the intensity of the fire. Less than optimum conditions in any of these factors can lead to the mismanagement and/or failure of bushfire management efforts. Out of these 4 factors, prevailing climatic conditions cannot be controlled by humans and they can cause major roadblocks in effective fire management. The level of fuel hazard and intensity of the fire are both dependent on the fuel source, which in turn is dependent on previous prescribed burning strategies and efforts. Time of mounting the initial response depends on the availability of suppression resources and ground crew, and the sufficiency of these resources and crew to suppress the fire. As a lot of factors are involved in managing even one bushfire, there is a very high possibility that anything could go wrong and cause the entire operation to fail and/or overwhelm the firefighters (CSIRO, 2009).

4.5.3 Limitations of Water-Bombing Aircraft

Water-bombing aircraft, although having the advantage of speed and accessibility, are not very useful in high intensity fires. This is because the speed at which the fire spreads is too high for the aircraft to overcome and suppress the flames. Also, the time taken for the aircraft to refill its resources and return to the site of the fire can result in loss of valuable time, causing the fire to potentially get out of control (Plucinski, 2007). These aircraft, without the active support of ground crews, cannot suppress a fire all on its own, neither can they prevent re-

ignition by removing smouldering and flaming fuels from the site of the initial fire. They can only lower the intensity of the fire behaviour, and only with the direct action of ground crews can they completely put out a fire.

4.6 Summary

Our results show that the bushfire management strategies that are implemented in the Northern Territory region are quite effective in controlling medium-intensity bushfires. They have a good monitoring system and they make use of fire danger alerts, emergency warnings, and fire-bans to inform the local communities of the imminent threat from bushfires. Apart from that, they make use of fire-breaks, prescribed burns or hazard reduction burns, water-bombing aircraft in collaboration with ground crews, and active volunteer recruitment for strengthening their bushfire management practices.

However, during most seasons when the climatic conditions are particularly bad or when the growth of gamba grass has gone out of proportions, the mitigation efforts by Bushfire NT and Bushfire CRC are not sufficient to handle the extremely high intensity and frequency of bushfires. Therefore, the current bushfire management strategies are only tailored to control bushfires to a certain extent; however, in extreme or unpredictable circumstances, the bushfire management organizations are overwhelmed and are not capable of bringing the situation under control. Even in the current bushfire season of 2020, it is already being predicted that the mitigation efforts being implemented may not be sufficient to keep the bushfires under control. Although gamba grass has been a threat to biodiversity of the Northern Territory region for at least over 50 years, efforts have been unsuccessful and/or minimal to remove this weed from the landscape. Also, regardless of the fact that the entire world is grappling with the extreme climatic conditions due to global warming, Northern Territory does not have a strategy to control bushfires in the face of extremely bad weathers. This places the region at a very vulnerable position with respect to bushfires after very heavy rainfall or an extremely dry season.

Chapter 5: Recommendations and Implications for Future Practice

5.1 Introduction

The previous chapter provided an in-depth case study analysis of the bushfire seasons of the past 10 years, focusing on the intensity of the fires, the risk factors that sparked and/or increased the severity of the fires, the pre-fire and post-fire management practices adopted, and the effectiveness of these practices based on the information available from online news sources. Based on this case study analysis, there were four major risk factors that were found to affect bushfires in the Northern Territory – gamba grass, extreme climatic conditions, non-compliance of citizens, and firehawks – although the latter two were found to contribute to a lesser extent. Each of the bushfire management practices adopted over the last 10 years were analysed in detail focusing on both their strengths and limitations.

This chapter aims to draw on the information and insights from the previous chapter and recommend specific strategies that can be applied in the Northern Territory context to manage future bushfires. The two major risk factors of gamba grass and climatic conditions have been addressed in detail and specific practices have been recommended to overcome these risk factors. Apart from that, fire detection and warning systems, and advanced remote sensing technologies have been elaborated taking examples from other countries around the globe and their applications in detecting and managing bushfires have been explored.

5.2 Risk Management with Respect to Bushfires

Some of the recent bushfire events such as the 'Black Saturday' which took place in February 2009 in Victoria took the lives of 173 people and caused immense materialistic damage which could have been easily avoided. Similar bushfire incidents in other parts of the world, especially in the United States and Europe, have resulted in significant financial and human life losses over the past few years. In the US alone, between the years 2002 and 2011, there has been a financial loss of $7.2 billion due to bushfires alone. It has since been proposed that although bushfires are inevitable, the extent of damage caused to human lives and

properties is within our control and we need to make the best of the available resources to prevent extensive damage due to bushfires (Calkin et al., 2014).

The first step to avoiding extensive damage caused by fires is risk assessment and risk management. Strategic risk management in the Northern Territory region should comprise of a thorough assessment of the probability that a bushfire will occur and the potential damage that it can cause to human lives and assets. This risk assessment should include historic predisposition to fires, the dynamic ecological processes that lead to the development of ecosystems, fuel hazards and possibility of fuel continuity, proximity of communities to fire-prone areas, and current community fire protection strategies in place.

A conceptual framework for bushfire management has been proposed by Calkin et al. (2014) as shown in Figure 5.1, which can be applied to the Northern Territory region with a few relevant modifications. This model proposes both fundamental and means-based objectives for bushfire risk management along with risk mitigation strategies to reduce the risk of bushfires to the local communities. The most fundamental objective of risk mitigation is preventing damage to human lives and domestic properties, and this can be achieved by eliminating the risk factors that make these properties susceptible to bushfires. Therefore, depending on the risk factors, risk mitigation objectives will vary in order to protect houses and buildings from damage. Other risk factors that are not within human control include landscape, climatic conditions, and ignition of fires due to lightning strikes.

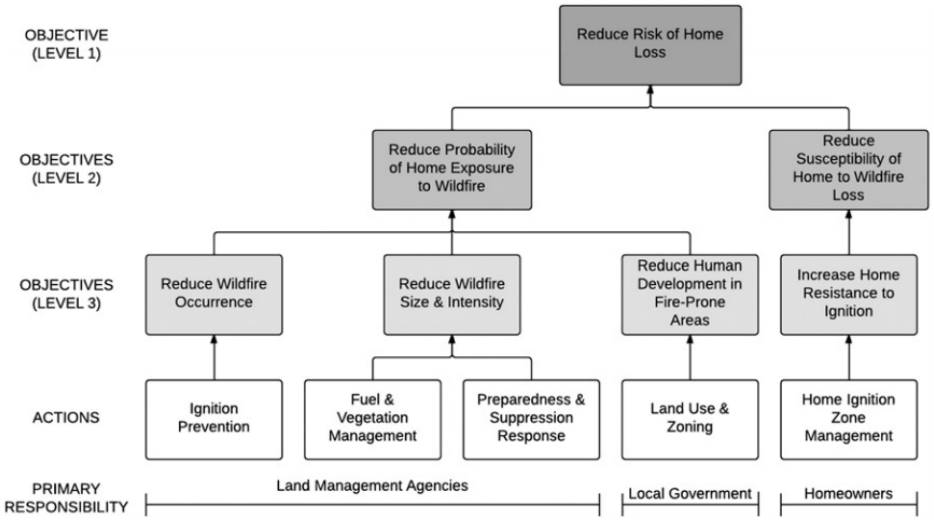

Figure 5.1: A conceptual framework for bushfire risk assessment and management (Calkin et al., 2014)

5.3 Early Fire Detection and Warning System

The disastrous effects of a significant number of bushfires can be avoided or reduced by early fire detection and warning systems in place. These 'fire intelligent' systems are developed such that they can evaluate the prevailing and forecasted climatic conditions, dryness of the vegetation, assessment of potential active fires, performing extensive risk assessment of vegetation cover, fire modeling, and dissemination of information among key stakeholders. One component of these 'fire intelligent' systems may be local indicators such as local weather conditions forecast and evaluation of dryness of local vegetation cover. Remote locations may be monitored through advanced technologies using data from remote sensing systems and international communication systems (Goh et al., 1999).

The lack of remote sensing technologies in the Northern Territory region is a major drawback as the use of these advanced technologies in local forest areas can provide valuable information regarding their fire risk and susceptibilities. Advanced space-borne technologies can provide in-depth and accurate evaluation of forecasted fire weather and assessment of vegetation dryness of large local regions as opposed to information collected using ground-based data acquisition techniques. Remote sensing technologies can also aid in detecting and

monitoring active fires in accessible as well as remote locations, thereby providing an extremely valuable tool for predicting the intensity and location of future wildfires (Goh et al., 1999).

The availability of regular satellite data regarding greenness of the vegetation cover and other risk factors over broad areas of land is extremely important to give an idea of the potential intensity of future bushfires. The extent of area occupied by live vegetation including its moisture content can provide significant insights into the possibility and severity of future wildfires. Currently, the assessment of vegetation cover is done by manual methods; however, this is not practical and accurate over large areas of land. An instrument like the NOAA Advanced Very High Resolution Radiometer (AVHRR) with wide-angle scanning radiometers has the capability of visualizing and assessing large areas of land at a single time. A lot of countries around the world are using this instrument to analyze vegetation cover, and to detect active fires and smoke, which helps them plan ahead for future bushfire seasons (Kendall et al., 1996). Currently, the Northern Territory government relies on satellite data obtained from NASA to inform them of potential fire weather conditions and detect active fires. Having an instrument like AVHRR in space which can provide local targeted information can help in serving as an early warning system for bushfires.

Development of fire danger maps using satellite data is another application of having one's own remote sensing instrument in space. The United States has developed extensive fire danger fuel model maps that provide a spatial distribution of different fuel sources in order to map the hazard levels of different regions (Loveland et al., 1991). Another example is Oklahoma that has an extensive network of 111 weather stations that acquires observational information every 15 minutes. This has ultimately contributed to the development of a fire danger rating system based on vegetation cover and weather conditions in different areas. Oklahoma now has a live fire danger map that shows an accurate and useful transition of fire danger levels across the different regions of the state (Carlson et al., 1996).

5.4 Management of Fires Caused due to Gamba Grass

5.4.1 The Problem

Gamba grass has been introduced into the Northern Territory from Africa in 1931 to address the problems of cattle grazing and production. It falls under the category of high biomass pasture grasses that grow faster than the native species of grasses. This results in a fast-growing grass species resulting in very high fuel loads which contribute to intense bushfires during the dry season. It has been estimated that gamba grass contributes to 7 time higher fuel loads than other native species of grasses in the Northern Territory region (Rossiter et al., 2003). As a result, the fires that are ignited due to gamba grass are 8 times more intense as compared to those ignited by native grass species. Additionally, the rate with which the fire spreads across the landscape is 5 times higher for gamba grass as opposed to other native grass species (Rossiter-Rachor et al., 2008).

Bushfires caused due to gamba grass have a devastating effect on the landscape, biodiversity, and the ecosystem. The management of this weed species increases the frequencies of fires because field owners need to burn them more frequently to lower fuel loads owing to their rapid growth rate. Its rapid growth also indicates that it re-grows soon after an intense fire increasing the chance of igniting another intense bushfire during the same season. As a result, fires caused due to gamba grass have the potential of reducing the entire tree cover of Northern Territory by 50% over a period of 12 years (Ferdinands et al., 2006). Gamba grass is considered to be an 'ecosystem transformer' as it has the capability of converting native eucalyptus woodlands into exotic grasslands by gradually eliminating all the native species of the region (Navie and Adkins, 2007).

5.4.2 Current Management Practices

One of the current initiatives of the Northern Territory for managing gamba grass in the region is 'The Territory Weeds Management Strategy (1996 – 2005)', which aims to control the spread of gamba grass and other weed species both into and within the Northern Territory region. It also tries to propose specific means by which the environmental problems caused due

to gamba grass can be overcome, and circulate these proposed practices among land owners so that they can implement these strategies on their fields. Another initiative was the 'Report on Invasive Species and Management Programs in the Northern Territory' prepared by the Legislative Assembly which proposed bringing the growth, management, and control of gamba grass throughout the region under legislative control (Legislative Assembly of the Northern Territory, 2008). The government of Northern Territory has also collaborated with Charles Darwin University to develop a Weed Risk Management System for the purposes of risk assessment and quantification of the management processes through a ranking system.

At the national level, the AusBIOSEC and Australian Weeds Strategy initiatives promote the risk assessment, management, and control of gamba grass and other weed species in all states and territories of Australia. However, these strategies do not propose specific threat abatement plans or specific actions required to be undertaken for the management of gamba grass. Therefore, the primary responsibility lies with individual state governments to manage weed species in their respective territories for the purpose of controlling the frequencies and intensities of bushfires in their regions.

According to current estimates, gamba grass occupies just a small portion of the entire Northern Territory region, and it is already leading to major destruction by igniting devastating and uncontrollable bushfires. Due to its rapid growth and expansion abilities, it has the potential to spread all across the savannah woodlands, floodplain margins, monsoon vine thickets, riparain zones, and open forests in the Northern Territory. Therefore, timely action is extremely necessary to avoid catastrophic bushfires that can result in the future due to ineffective control of gamba grass (Setterfield et al., 2013).

5.4.3 Recommendations for Improved Management

We propose the development of a regional comprehensive Threat Abatement Plan for the management and control of gamba grass involving all stakeholders such as local municipalities and landowners. This plan will include:

- A description of all control methods for gamba grass, both currently in use as well as those that can be potentially applied
- An expert review of the assessment of efficiencies of these control mechanisms
- An overview of the rates and mechanisms by which gamba grass grows and spreads
- An extensive discussion of the specific actions that need to be taken to control and/or eliminate the spread of gamba grass
- An analysis of the characteristics of high biodiversity regions and the infestation of gamba grass in these regions
- An analysis of environmentally significant regions and the distribution of gamba grass in these regions
- Development of a database comprising of maps and control measures of each sub-region for information curation purposes
- Proposal of incentives and rewards for excellent management of gamba grass in privately owned lands
- Implementation of educative seminars and workshops to provide information and resources to landowners regarding practices and strategies for control of gamba grass

Apart from such a plan of action, there are several scientifically proven ways by which the growth and spread of gamba grass can be controlled in the Northern Territory. One of them is the use of herbicides such as dalapon and sulfometuron, which has reduced the cover of gamba grass by 90% in the areas tested. Another approach is use of the herbicide glyphosate for the control of mature gamba grass plants. Physical techniques include mulch cover and scarification, and biological techniques include competition strategies; however, there is a clear need for better and more effective strategies for gamba grass control (Luck et al., 2019).

As prescribed burning is one of the primary strategies for bushfire management in the Northern Territory region, specific care needs to be taken to perform these mitigation burns so as not to cause accidental intense fires in gamba grass fields. Additionally, for high biomass grasses such as gamba grass, use of machinery and fire vehicles can further help in spreading the seeds of the weed species to distant locations. Therefore, it needs to be ensured that the

efforts invested in controlling gamba grass do not end up further spreading the weed species. In certain cases, it has been recommended not to use prescribed burning for controlling bushfires caused due to gamba grass as it can have potentially disastrous effects if not managed properly. Reports suggest that prescribed fires should be used before the seeding stage of gamba grass as flames can carry seeds to distant locations and start renewed growth of gamba grass. Also, application of strong herbicides after a prescribed burn has been shown to actively curb the growth of gamba grass following the fire (Neldner et al., 2018).

5.5 Management of Fires Caused due to Extreme Climatic Conditions

Managing bushfires that are caused as a result of extremely hot and dry periods preceded by intense rainfall is challenging as climate is a risk factor that is beyond human control. Therefore, in order to overcome the danger of bushfires due to climatic conditions, we need to make our landscapes and forests resilient to extreme temperatures in order to prevent extremely frequent and intense bushfires. Some of the 'climate smart' strategies that have been proposed and implemented worldwide include stand density management, control of invasive weed species (in this case, gamba grass), and reduction of fuel sources from the surface layers in forests (Peterson et al., 2011).

A period of extremely dry climatic conditions is one of the major risk factors for intense bushfires in the Northern Territory. As such a condition is unpredictable and can lead to uncontrolled fires, it is important to prepare for it beforehand. Appropriate fuel treatments can reduce fire intensities during a dry season and crown fire potential can be reduced by decreasing the forest densities. Even if the forest type is wet, a decrease in stand density can increase the amount of available water thereby enhancing tree growth and vigour by eliminating competition. Overall, decreasing the stand density in either a wet or a dry forest along with targeted fuel treatments has been shown to increase resilience of the forest to high-intensity wildfires (Agee and Skinner, 2005). Another strategy that has been shown to work is forest thinning in dry climatic conditions that can further aid reduction in forest density. This approach not only increases a forest's resilience to wildfires, but also to drought and insects (Sohn et al., 2016).

In contrast, in conditions of heavy rainfall, studies have shown that fuel treatments and reduction in forest density might not be useful in reducing fire severity (Halofsky et al., 2018). Thus, in order to reduce fire severity following a period of very heavy rainfall, fuel breaks can be installed around watersheds, wildlife habitats, and other infrastructure to manage potential high-intensity wildfires. Another approach might be to promote heterogeneity in the landscape by encouraging growth of diverse species and removing invasive species such as gamba grass from the forests (Syphard et al., 2011).

Regeneration of forests after extremely catastrophic fires is also important to re-build the forest's resilience to potentially devastating climatic conditions in the future. This can be done by increasing the available seed sources by means of promoting reproduction of live residual trees following a fire (Dodson and Root, 2013). If there are still green trees left after a fire, then methods of natural regeneration may be enough. In addition, planting new trees may further aid in the natural regeneration process where damage due to wildfires is not very extensive. If planting new trees is a viable option, then stock density may be lowered and the spatial heterogeneity may be increased, that will help in increasing resilience to drought and forest fires (North et al., 2019).

5.6 Community-based Fire Management Strategies

Many local communities around the world have adapted to fires and use it productively for agriculture, cattle grazing, and managing forest products. This is possible because most people who live in fire-prone areas recognize the intricate relationship they have with fire and their ecosystems. Although most communities effectively manage fire in their regions, their approaches are guided by gut feelings rather than scientific evidence, which can be both good and bad for current bushfire management practices. Therefore, an integrated community-based fire management approach using insights from indigenous communities and encouraging all local communities to participate can have far-reaching effects in reducing the intensity of bushfires and damages that result from these incidents.

In a typical community-based fire management approach, there are three players that contribute to different degrees to make such a program a success. The first one is local or

indigenous communities who possess a wealth of knowledge regarding safe and effective fire management practices, and use it as a means to maintain the landscape as well as their livelihoods. The second important player is the local stakeholder organizations such as environmental agencies and non-governmental organizations (NGOs) that are involved in fire management in their local regions. Although these agencies are placed in the appropriate position as a link between regional institutions and the local people, they may need assistance in fire analysis, technical resources, and logistics to carry out their fire management practices. The third key stakeholder is the volunteer community which assesses both private and public properties for fire management requirements and opportunities. The volunteers are representatives of the localites and understand their needs and practices well; therefore, they are in the perfect position to deliver fire management initiatives in their local communities (FAO, 2011).

Although indigenous fire management practices have been around since centuries and they have been effective to a considerable extent, it has been shown that these practices, if not governed by appropriate legislative policies and frameworks, can end up doing more harm than good. Therefore, before giving authority to local communities to practice fire management, it is important to set up policies, laws, and regulations in order to keep these practices under governmental control and this needs to be done at three stages – national, provincial, and local stages. At the national stage, appropriate policies and rules need to be devised to bring all fire management practices under an evidence-based unifying framework. At the provincial stage, environmental agencies need to promote the management of natural resources in the context of their specific forest types and fire potentials. At the local stage, policies need to govern the use and management of financial and material resources for fire management appropriately and hold accountability for the use and misuse of these resources (Treue and Nathan, 2007).

5.7 Implications for Future Practice

From our analysis, we have identified both strengths and limitations of current bushfire management practices in the Northern Territory. It is quite evident that most current strategies such as prescribed burning, volunteer programs, weed management programs, and use of

water-bombing aircraft are the strengths of fire management in the Northern Territory and are quite effective in controlling fires in this region. However, as is apparent from the current catastrophic bushfires taking place in the Northern Territory, it has become evident that there are definite gaps in the current bushfire management practices.

Based on our analysis, we found that there is a lack of targeted fire management practices which focus on specific risk factors and aim to reduce and/or eliminate them. The two most important risk factors, namely gamba grass and extreme climatic conditions, need to be addressed separately in order to bring down their contribution to the frequencies and intensities of bushfires in the Northern Territory. The previous sections have presented several specific strategies such as use of herbicides and targeted prescribed burns for addressing these risk factors, and these need to be implemented strategically to see positive results. Gamba grass has emerged as a particular threat to the vegetation of the Northern Territory, and they not only cause devastating bushfires, but also threaten the local biodiversity. Use of herbicides need to be employed on a large scale in order to eliminate this weed from the Northern Territory. Several options of herbicides and their combinations are available, and they can be selected based on the extent of infestation and the specific area that needs to be treated.

Apart from eliminating gamba grass, the Northern Territory needs to acquire advanced technological systems for detecting, monitoring, and acquiring data from active fires and present climatic conditions. Currently, the region relies on pictures and data provided by NASA's satellites; however, having a local satellite that can constantly monitor weather conditions, vegetation cover, and fuel hazards can go a long way in providing an early and accurate fire detection and warning system. Fuel hazard maps can be created up to a scale of 1 km which can focus efforts of agencies and other legislative bodies in managing fires.

Finally, a community-based approach may be essential here as indigenous communities have a very close relationship with forest ecosystems and their knowledge is extremely significant in the prediction and management of wildfires. Although some of their strategies are currently adopted such as prescribed burning, they need to be involved to a greater degree to aid with site selection and the range of the fire to be lighted. At the same time, the practices

suggestedby indigenous communities need to be governed by legislative policies so that there is a strong theoretical and structural framework for implementing fire management practices across the entire Northern Territory region.

5.8 Final Conclusion

In conclusion, this thesis aimed to identify gaps and limitations of the current bushfire management practices adopted in the Northern Territory region through a case study approach. We performed an in-depth case study analysis of the bushfire seasons of the past 10 years to identify the bushfire management practices being adopted currently. We found that the most common fire management strategies in use currently were prescribed burning, installation of fire breaks, circulation of fire danger warnings and emergency alerts, use of water-bombing aircraft and ground crews for putting out active fires, and sourcing information from NASA regarding fire weather and vegetation cover that predisposed the region to potentially catastrophic fires. The four main risk factors that were identified for leading to bushfires in the Northern Territory were widespread infestation of the weed species, gamba grass, extreme climatic conditions comprising of heavy rainfall followed by an extremely dry period that results in increased fuel loads, non-compliance of citizens with governmental rules regarding prevention of accidental fires, and fire-hawks that have the capacity to spark fires in distant locations to catch their prey.

Based on our analysis, there are no targeted steps being taken currently to address the problem of gamba grass infestation. Considering that this is the most important risk factor for catastrophic fires in the Northern Territory region, it is extremely important that targeted measures such as use of herbicides and reduction of competition be taken in order to decrease and/or eliminate this weed species from the region. Another recommendation is acquisition and use of advanced remote sensing technologies that can serve as an early fire warning system by providing continous data regarding fire weather and vegetation cover that can help in understanding the distribution of fuel loads across large areas of land. These measures will help in targeting the current fire management efforts appropriately so that the risk factors are

eliminated strategically and fire becomes more of a positive phenomenon for landscape and biodiversity rather than a catastrophic event for human lives and properties.

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