Northern Australia Environmental Resources Hub

National Environmental Science Programme

Savanna fire regimes and biodiversity impacts in northern Australia

Final report

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Cover photographs

Front cover: Rangers look on at a Cape York savanna burn (photo Anders Zimny).

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This study has been approved by CSIRO’s Social Science Human Research Ethics Committee in accordance with the National Statement on Ethical Conduct in Human Research (2007): ethics approval 130/20.

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Acronyms and abbreviations

ACCU .... Australian Carbon Credit Units

ACRIS .... Australian Collaborative Rangelands Information System

ARP .... Arnhem Plateau

AWC .... Australian Wildlife Conservancy

BILBI .... Biogeographic modelling Infrastructure for Large-scaled Biodiversity Indicators

BoM .... Bureau of Meteorology

CSIRO .... Commonwealth Scientific and Industrial Research Organisation

DAC .... Darwin Coastal Bioregion

DAWE .... Department of Agriculture, Water and the Environment

EPBC Act ...... Environmental Protection and Biodiversity Conservation Act

HCAS .... Habitat Condition Assessment System

IBRA .... Interim Biogeographic Regionalisation for Australia

ICIN .... Indigenous Carbon Industry Network

LRF .... Land Restoration Fund

LTERN .... Long-Term Ecological Research Network

MER .... Monitoring, Evaluation and Research

NAILSMA ...... North Australian Indigenous Land and Sea Management Alliance

NESP .... National Environmental Science Program

NT .... Northern Territory

PCK .... Pine Creek

QLD .... Queensland

TERN .... Terrestrial Ecosystem Research Network

UNFCCC .... United Nations Framework Convention on Climate Change

WA .... Western Australia

Executive summary

In this project, we completed a detailed review of the available published literature on the impacts of fire regimes on biodiversity in northern Australia. We analysed the key drivers of different fire-management regimes in northern Australia and produced summaries of the patterns of fire across different land-use types. We convened 2 virtual workshops that were attended by 45 fire and biodiversity experts from 17 research, government and non-government institutions. We secured the services of two Indigenous organisations (North Australia Indigenous Land and Sea Management Alliance [NAILSMA] and Djarnda Enterprises – Barry Hunter) to gather information from key land-use sectors across northern Australia, in order to gain feedback on the requirements for a robust and ethical process for recording the diverse views of fire managers across the region.

In our systematic review, we produced a database of the available literature. We identified 270 original research papers, 14 theses and 3 book chapters containing original data, analysis or results, and other grey literature sources. Most of the literature was produced in the past 20 years and was dominated by studies conducted in the mesic savanna of the Darwin Coastal Bioregion. This exposed a significant knowledge gap in research that encompasses the diverse range of habitat and climatic types across northern Australia. Most studies did not provide clear links between fire regimes and biodiversity patterns. When considering positive or negative impacts from late dry-season fire, there were mixed results at the community level. Most studies did not specifically test fauna response to early and late dry-season fire as defined by the savanna burning methodology.

Very few studies attempted to understand mechanisms of response describing declines. Rather, they focused on limited one-off studies quantifying the short-term impacts of fire (e.g. single fire events or coarse fire-frequency metrics). Our review has highlighted the paucity of longitudinal studies that consistently implement an experimental design with study length less than 10 years. For vertebrate fauna, the time scale that these studies are being conducted across does not account for the inherent time lags that are likely to be associated with species recovery following persistent landscape scale fire regime shifts.

Filling pertinent knowledge gaps requires a coordinated and strategic approach across the fire-management and research communities to efficiently share and utilise resources and collective knowledge.

1. Introduction – fire regimes and biodiversity in northern Australia

Savanna burning has a long history in Australia, with Aboriginal use and management stretching back for millennia. Across northern Australia, it is a landscape-scale activity that affects vegetation and biodiversity. Many factors affect the frequency and timing of burning including land tenure (e.g. protected areas, pastoral, Indigenous land) and related management objectives (e.g. biodiversity, emissions trading, grazing, weed management, fire prevention). The various fire-management aspirations for Indigenous land have been well described in the literature (e.g. Ansell et al. 2019) and continue to be the focus of discussion at annual north Australia savanna fire forums (savannafireforum.net).

The impact of different fire regimes on biodiversity is of global interest and is a common aim of many savanna fire-management programs. This project reviewed the current burning regimes in northern Australia and the existing understanding of their relationship to biodiversity conservation. A key driver of change to savanna burning regimes in recent history has been the implementation of a regulated greenhouse gas abatement methodology. The savanna burning methodology promotes the change of fire regimes from predominantly late dry-season, intense fires to lower-intensity, lower-emissions, early dry-season fires. This is achieved through the promotion of early dry-season fire, which decreases fuel loads and reduces the risk of extensive late dry-season fire. Although the incentive for savanna fire-management is centred on carbon reduction, there are many different reasons why fire management is applied and these change across and within tenure types. In this project, we completed a broad-scale assessment of historical fire regimes in major land use types across the region, using remote sensing, to explore broad trends in fire management between sectors.

This report summarises the results from the following activities:

1. Complete a desktop review of the impacts of fire on biodiversity in savanna landscapes (incl. 600–1,000 mm rainfall zone), including evidence that informs improved long-term fire management
2. Describe current fire-management regimes (i.e. fire frequency, scale and seasonal timing of burning) and review their differences and impact on biodiversity
3. Synthesise contemporary policy and management influences on savanna burning (i.e. savanna emissions burning methodology)
4. Provide a summary of existing monitoring methods to support options for designing monitoring programs to demonstrate biodiversity impacts from savanna burning
5. Undertake strategic meetings with researchers with experience in fire and biodiversity impacts to identify gaps in peer-reviewed research, and identify if there are strategic publications that could fill the exposed gaps that can use existing data sets

6. Participate in a workshop with key savanna burning stakeholders facilitated by the Department of Agriculture, Water and the Environment, including the following elements:
    a. Review data availability and willingness of land managers to participate in future monitoring and on-ground adaptive management
    b. Identify, prioritise and scope potential future research and monitoring activities.

2. Complete a desktop review of the impacts of fire on biodiversity in savanna landscapes (incl. 600–1,000 mm rainfall zone), including evidence that informs improved long-term fire management

This section includes a summary of the manuscript ‘Fire ecology research in Australia’s tropical savanna: filling the gaps’ (in preparation). The draft manuscript is currently undergoing scientific and stakeholder review and is intended to be submitted for publication by 30 September 2021.

2.1 Introduction

Tropical savannas of northern Australia are highly flammable ecosystems, and purposeful management of fire by First Nations people over thousands of years has shaped their ecology. Disruption of traditional fire management has resulted in higher fire frequencies and intensities over recent decades. Recognition of the link between strategic fire management and greenhouse gas emissions abatement has led to the successful implementation of savanna burning methodologies across a third of northern Australia. However, there is limited understanding of the response of biodiversity to re-introduction of strategic fire management.

In this review, we summarise research describing the effect of fire on biodiversity in the tropical savanna biome of Australia (including terrestrial and aquatic flora and fauna, and abiotic components), by drawing together peer-reviewed publications and grey literature (including unpublished reports and datasets). We quantify the number of studies over time, their geographic distribution, taxonomic groups studied, the methods and lines of investigation used, and summarise broad patterns in the results. We highlight where further research could be conducted to fill critical knowledge gaps.

2.2 Methods

The title, abstract and keywords of all peer-reviewed literature in the Scopus database were searched on 1 September 2020, using the phrase ‘savanna%’ OR ‘monsoon%’ AND ‘%fire%’ OR ‘burn%’ OR ‘disturb%’ OR ‘decline’ AND ‘Australia%’. This returned 658 publications. The abstract of each publication was read, and literature was selected that:

- pertained to the tropical savanna biome of Australia (>600 mm rainfall)
- experimentally tested or observed the effect of a fire or fire regime on an abiotic or biotic component of a savanna ecosystem
- was a peer-reviewed primary research paper, thesis, or book chapter, or conference proceeding that contained original or previously unpublished research, or contained a novel approach to analysis of previously published studies (e.g. meta-analysis).

Review papers, and books or book chapters relevant to the savanna biome in Australia but containing only secondary information, were collated and used to cross-reference our initial list of peer-reviewed papers and identify literature not captured by our search terms.

We presented a summary of compiled literature at two online workshops (16 and 22 October 2020), targeted at prominent savanna burning experts, to identify additional research papers, grey literature, data and other publications relevant to this study (see Section 6).[1]

The metadata identifying the type of document, geographic location of study, bioregion, rainfall, broad vegetation community, methodological or experimental design, taxonomic groups studied, fire response parameters, and responses of biodiversity were extracted from each paper and collated to identify broad trends in the literature.

2.3 Results

We identified 281 original research papers, 13 theses and 4 book chapters containing original data, analysis or results. There also were 23 conference proceedings and 22 reports or grey literature items containing otherwise-unpublished data, analysis or results. In addition, there were 30 review articles, 6 books and 17 book chapters providing reviews or synthesis of ecological effects of fire in the Australian tropical savanna biome. This was turned into an interactive summary.

The locations of fire ecology studies (original peer-reviewed research) in the Australian tropical savanna were unevenly distributed across each of the 21 constituent Interim Biogeographic Regionalisation for Australia (IBRA) regions. Studies within the Darwin Coastal (DAC; 105 studies), Pine Creek (PCK; 49 studies), and Arnhem Plateau (ARP; 29 studies) bioregions were over-represented in the literature (Figure 2.1).

[1] Workshops were conducted in accordance with the *Australian National Statement on Ethical Conduct in Human Research (2007) updated 2018:* CSIRO's Social Science Human Research Ethics Committee (ethics clearance 130/20).

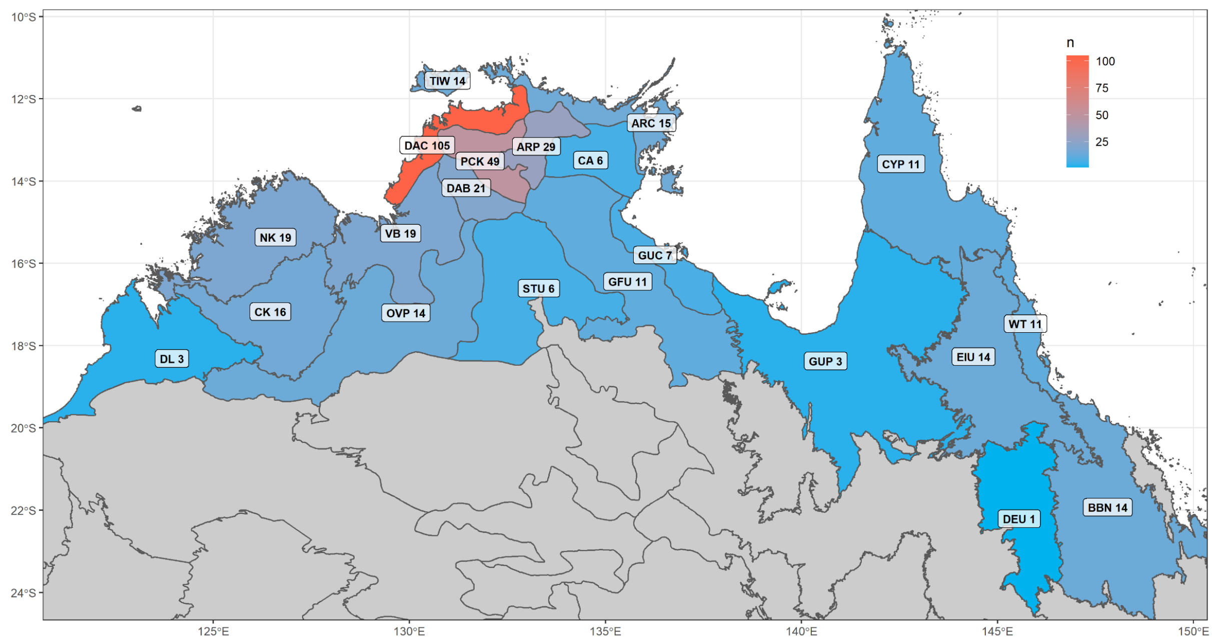

Figure 2.1. Number of peer-reviewed empirical studies researching the ecological effects of fire within each bioregion of the Australian savanna biome.

The responses of flora to fires in savanna ecosystems have been studied most, and for the longest time, followed by fauna. Abiotic and aquatic biota have been investigated few times overall (Figure 2.2). Mammals (except bats), birds, invertebrates and reptiles are relatively well studied compared to other faunal groups (Figure 2.3).

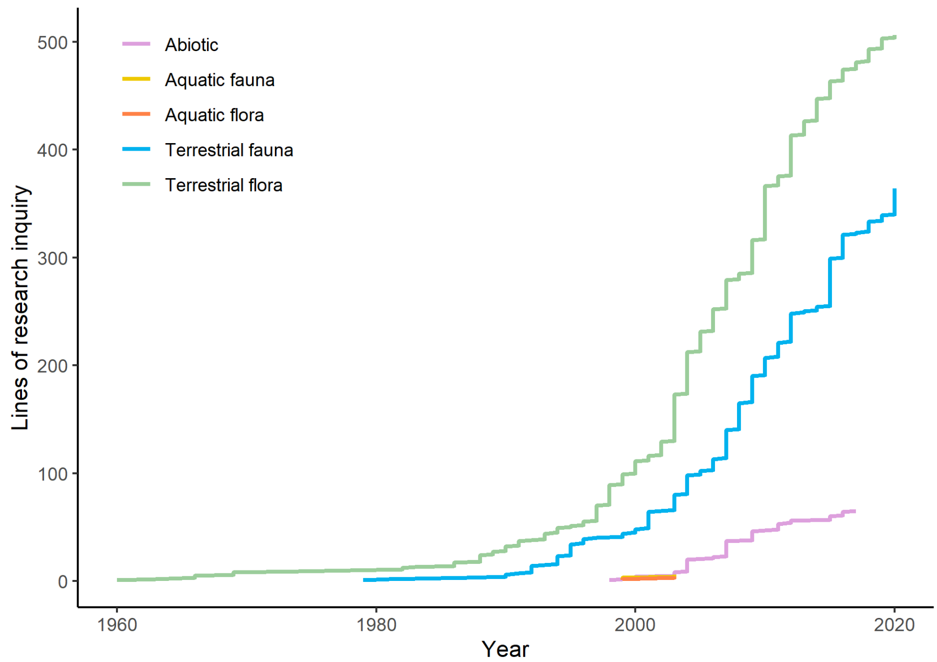

Figure 2.2. Cumulative lines of research inquiry into ecological effects of fire in Australian savannas for different ecological groups in peer-reviewed research over time.

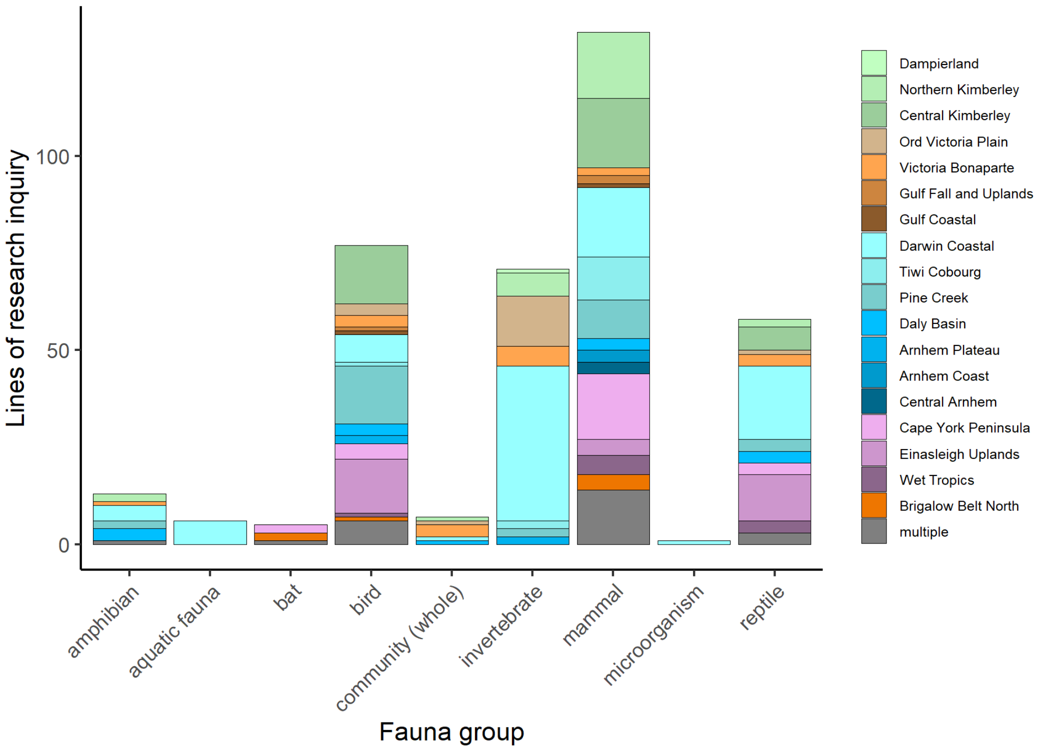

Figure 2.3. Unique lines of research inquiry into ecological effects of fire in Australian savannas for faunal groups.

Published research documents a wide range of responses of biodiversity to different components of fire regimes. The manuscript details responses (abundance, richness, composition and behavioural responses) in terms of decreases, increases or no change for taxa groups in each bioregion. Gaps were also identified for each taxa group in terms of geography and functional groups within the taxa, and methodological issues are highlighted.

2.4 Discussion

While there has been an increase in the number of publications assessing the response of biodiversity to fire regimes in the savannas, these are geographically biased. Compared to the Northern Territory, Western Australia and Queensland have significantly fewer publications. This is of concern because applying results from the Northern Territory to other areas may be inappropriate due to inherent differences in the ecology and fire seasons of these regions (Perry et al. 2019).

Research is also taxonomically biased with some faunal groups receiving very little attention (e.g. amphibians, other aquatic fauna). Even within taxa, the response of biodiversity can be variable depending on the fire regime component being assessed, the geographic location, and the methodology and timeframe of the research. Vegetation structural components of biodiversity exhibit relatively more consistency in response to fire regimes than fauna or flora species-specific, or compositional responses. For example, most studies that assessed vegetation biomass responses documented reductions as a result of higher fire intensity and late dry-season fires. Research on the response of reptiles, for example, documents species that increase, decrease, or show no change in abundance, even within the same bioregion and in response to the same fire regime.

Given ongoing savanna burning programs in Australia and climate change impacts on fire behaviour, the information in this review highlights additional research and knowledge needed to understand biodiversity responses to fire in the savannas.

3. Describe current fire-management regimes (i.e. fire frequency, scale and seasonal timing of burning) and review their differences and impact on biodiversity

3.1 Introduction

Fire regimes describe the pattern of spatial and temporal variation in fire intensity, seasonality, severity and frequency in a particular area, thereby providing a critical foundation for understanding the occurrence of fire in the landscape, and its effects on ecosystems and atmosphere (Gill 1975; Bradstock et al. 2002).

Globally, fire is a major driver of the distribution, structure and ecological function of many ecosystems (Gill 1975; Moritz et al. 2014; Davies et al. 2021; Bradstock et al. 2002). Savannas – tropical and subtropical vegetative formations with continuous grass cover under a sparse layer of trees (Maraseni et al. 2016; Russell-Smith et al. 2013; Andersen et al. 1998) – are among the most fire-prone biomes on earth (Andersen et al. 2005; Russell-Smith et al. 2007; Perry et al. 2019; Edwards et al. 2021; Andersen et al. 2012). As such, the development of ecologically sustainable fire-management regimes within savanna biomes is critically important for maintaining biodiversity and ecosystem function.

In northern Australia, tropical savannas cover over 2 million km^2, and represent approximately 12% of global tropical savanna ecosystems (Maraseni et al. 2016; Perry et al. 2020). The region is subject to a strong seasonal tropical monsoon, followed by a long warm dry season of 6 to 9 months which receives little to no rain and is highly fire-prone (Russell-Smith et al. 2000; Cook and Heerdegen 2001), with fire frequency across Australian savanna being among the highest in the world (Andersen et al. 2005; Russell-Smith et al. 2007).

The tropical savanna regions of northern Australia have been historically managed by Indigenous peoples utilising fire for millennia (Andersen et al. 2012; Fache and Moizo 2015; Ansell et al. 2019; Evans and Russell-Smith 2020; Preece 2013), with the native flora and fauna adapting and co-evolving with these burning regimes (Bird et al. 2005). Following European settlement in the 19th Century, disruption to these burning practices led to reduced fire-management within these areas. As such, fire regimes have moved into an unnatural state, with increased fire frequency and intensity leading to declines in regional biodiversity and reduced ecosystem function (Russell-Smith et al. 2007; Andersen et al. 2012; Woinarski et al. 1999).

Recent uptake of new carbon-abatement and sequestration methodologies (Commonwealth of Australia 2012, 2015, 2018) – focused on savanna burning regimes and modelled on traditional burning practices – have the potential to shift regimes back towards more ecologically sustainable states. Savanna burning methodologies have been developed to reduce the risk of increased fire size and intensity (i.e. more destructive fires) through the promotion of fires earlier in the dry season, thereby decreasing fuel loads before they can build to levels that promote destructive fires (Beringer et al. 2015). These methodologies have been validated and approved within areas of northern Australian savanna, specifically within the zones where annual rainfall is between 600 and 1,000 mm (low rainfall zone) and above 1,000 mm (high rainfall zone; Commonwealth of Australia 2012, 2015, 2018; Figure 3.2). In recent years, the adoption of these methodologies has led to a change in fire practices across northern Australia (Ansell et al. 2019) and subsequent overall decreases in fire size, intensity and seasonality along with an increase in the number of small mosaic fires during the early dry season (Figure 3.3; Figure 3.4; Figure 3.5; Appendix 3).

Land tenure across northern Australia consists primarily of a variety of private agricultural land (primarily grazing of natural or semi-natural systems), Indigenous-owned lands and public and private conservation estates (Figure 3.2b). The uptake of savanna burning methodologies and fire-management regimes varies across land tenure types in accordance with their respective needs.

3.1.1 Conservation estates (public and private)

Conservation estates (public and private) occupy a significant proportion (12.3%) of Australia's tropical savanna zone (Figure 3.2b). These areas are managed primarily for the protection of native biodiversity through invasive-species control activities (pests and weeds), habitat protection and restoration and fire management. Within these areas, management of fire is primarily carried out to maintain or increase the complexity and patchiness of regions at the landscape scale (Woinarski et al. 2005). Additionally, management for protection of specific fire-prone or dependent species occurs within some areas. Across the last 20 years, the peak fire season in conservation lands has remained relatively stable, occurring predominantly across the beginning of the late dry-season period (Figure 3.3 and Appendix 3). However, like other tenure types, fire size and area has decreased throughout this period (Figure 3.4; Figure 3.5; Appendix 3).

3.1.2 Indigenous

Management of land on Indigenous estates has traditionally focused on managing land to care for Country and protect or restore cultural and natural resources (e.g. bush tucker) (McKemey et al. 2020; Yibarbuk et al. 2001; Ansell et al. 2019). In contemporary times, there has been a trend of Indigenous peoples leaving or being moved from Country, which has created a loss in traditional fire management across these (and other) regions (McKemey et al. 2020; Cooke 2009). This has led to an increase in late-season fuel loads, resulting in increased fire frequency, size and intensity (Figure 3.5). However, Indigenous-managed lands have undergone the most significant changes to fire management with the implementation of the savanna burning carbon-abatement and sequestration methodologies; with the new programs providing a major source of untied revenue and employment opportunities in community and ranger-focused activities (Ansell et al. 2019). Adoption of these methodologies across Indigenous lands has drastically decreased fire frequency, size and intensity (Figure 3.1; Figure 3.5) with marked changes in fire seasonality with shifts towards early dry-season fires (Figure 3.3; Figure 3.4).

3.1.3 Pastoral

Pastoral land accounts for 67% of the northern tropical savanna region. Despite being classed as an intensive land-use type, much of this land retains an unmodified state, consisting of native pasture grasses and vegetation (Woinarski and Braithwaite 1990). The primary activity is the production of cattle for sale into beef markets. As such, management of fire within these tenures revolves around promoting pastorally productive grass (green pick), extending pasture growth, asset protection and weed management (Russell-Smith et al. 2020). More recently, pastoral lands have begun to adopt the savanna burning carbon methodologies as an additional source of revenue. Across the last 20 years, changes in fire size have followed the general trend for the region, decreasing in size, particularly following the implementation of the savanna burning methodologies in 2012 (Figure 3.5). With respect to peak fire month, overall seasonality of fire has remained similar across these years, with a trend for more fire during the late dry season (Figure 3.3).

3.1.4 Defence

While Defence land falls under the Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act) as Commonwealth land – requiring land to be managed to high conservation standards – primary management goals are to safeguard human life and property. Hence, there is a propensity to burn sizeable tracts of land over a short time frame as part of the Department of Defence's annual bushfire mitigation works. On average, the Department of Defence burns 44% of its land via early season burns (Figure 3.3) – twice the amount of burning that occurs on Indigenous-owned land (22%) (Brann 2020). These large, non-mosaic styled burns do not prioritise conservation values.

3.1.5 Mining

Mining tenures cover both areas under intensive mining activities, areas set aside for future mining activities, land being restored from previous mining activities and areas managed to offset the loss of local biodiversity. Consequently, fire-management regimes within these areas differ depending on the current state or use of the land. For example, land under restoration is managed for conservation values, with early season mosaic burning or weed suppression burning, while land being actively mined is managed for the protection of assets.

3.1.6 Municipal (townships)

Fire management on these lands is almost solely focused on the protection of life, property and assets, rather than conservation and biodiversity values. As such, management activities focus on the suppression of fire through controlled burning during the early dry season (Figure 3.3).

3.1.7 Minimal use and other

The classification of minimal use and other within our study represents the aggregation of multiple and varied land-use types, which did not fall within other land tenure types. Management within these zones is, thus, difficult to describe and idiosyncratic.

3.2 Methods

3.2.1 Savanna classification

Tropical savanna habitat (Queensland Government 2014) extent was downloaded from the Queensland Spatial Catalogue and used as the spatial extent of all analyses.[2]

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[2] https://qldspatial.information.qld.gov.au/catalogue/custom/search.page?q=%22The%20vegetation%20of%20the%20tropical%20savannas%20-%20Australia%22

3.2.2 Rainfall zones

Gridded climatological (30-year averages) data of annual rainfall (Australian Bureau of Meteorology 2020) were downloaded from the BoM website.[3] Data were classified into three separate zones following the breaks in rainfall used in the savanna burning methodologies (Commonwealth of Australia 2018) – that is, 1,000 mm and above (high rainfall), 600–1,000 mm (low rainfall) and <600 mm (very low rainfall).

3.2.3 IBRA (Interim Biogeographic Regionalisation for Australia)

Interim Biogeographic Regionalisation for Australia bioregions (Department of Agriculture Water and the Environment 2020) were downloaded from the Australian Government website.[4]

[3] http://www.bom.gov.au/jsp/ncc/climate_averages/decadal-rainfall/index.jsp?maptype=30&period=1986-2015&product=totals#maps
[4] http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B4A2321F0-DD57-454E-BE34-6FD4BDE64703%7D

3.2.4 Land tenure classification

Land tenure information was derived from a combination of the Catchment Scale Land Use of Australia (ABARES 2021) and Australian Land Tenure (Geoscience Australia 1993) datasets. The Australian Land Tenure dataset was not used as a primary source of information, as the most recent available version was from 1993, at least 7 years earlier than the fire data used in the current study. Individual land-tenure classes were defined as aggregations of representative land-use classes from (ABARES 2021). Where public or private ownership was unclear, the Australian Land Tenure 1993 dataset was used to split the classification. Rules and land-use classes used to define each land-tenure dataset are detailed in Table 3.1.

Table 3.1. Land-use classification used in the analysis.

Tenure type	Description
Conservation (public)	1.1 and 1.2 land use in secondary level of classification, intersected with public land tenure lots from the Australian Land Tenure 1993 dataset
Conservation (private)	1.1 and 1.2 land use in secondary level of classification, intersected with private land tenure lots from the Australian Land Tenure 1993 dataset
Pasture	All classes defined as grazing with secondary classification
Defence	All classes defined as defence land and facilities within tertiary classification
Indigenous	Single class 1.2.5 traditional Indigenous uses within tertiary classification
Minimal use	1.3 Other minimal use in secondary level classification
Mining	5.8 Mining in secondary level classification
Municipal	5.4 Residential and farm infrastructure in secondary level classification
Other	All remaining land-use classes

3.2.5 Fire frequency, timing and area

Fire data were downloaded from the North Australia and Rangelands Fire Information website,[5] as annual fire scars and rasters representing fire frequency, late-season fire frequency and time since last burn. These data were intersected with land tenure, rainfall and IBRA bioregions. For each individual class of data (e.g. public conservation land or rainfall zone), the mean fire size, month of the year where the most fires occurred, fire frequency and late-season fire frequency were calculated.

[5] https://firenorth.org.au/nafi3/

Data summaries, figures and summary statistics were derived using spatial tools in ArcMap 10.4.1. Graphs were derived using the R statistical environment (R Core Team 2017).

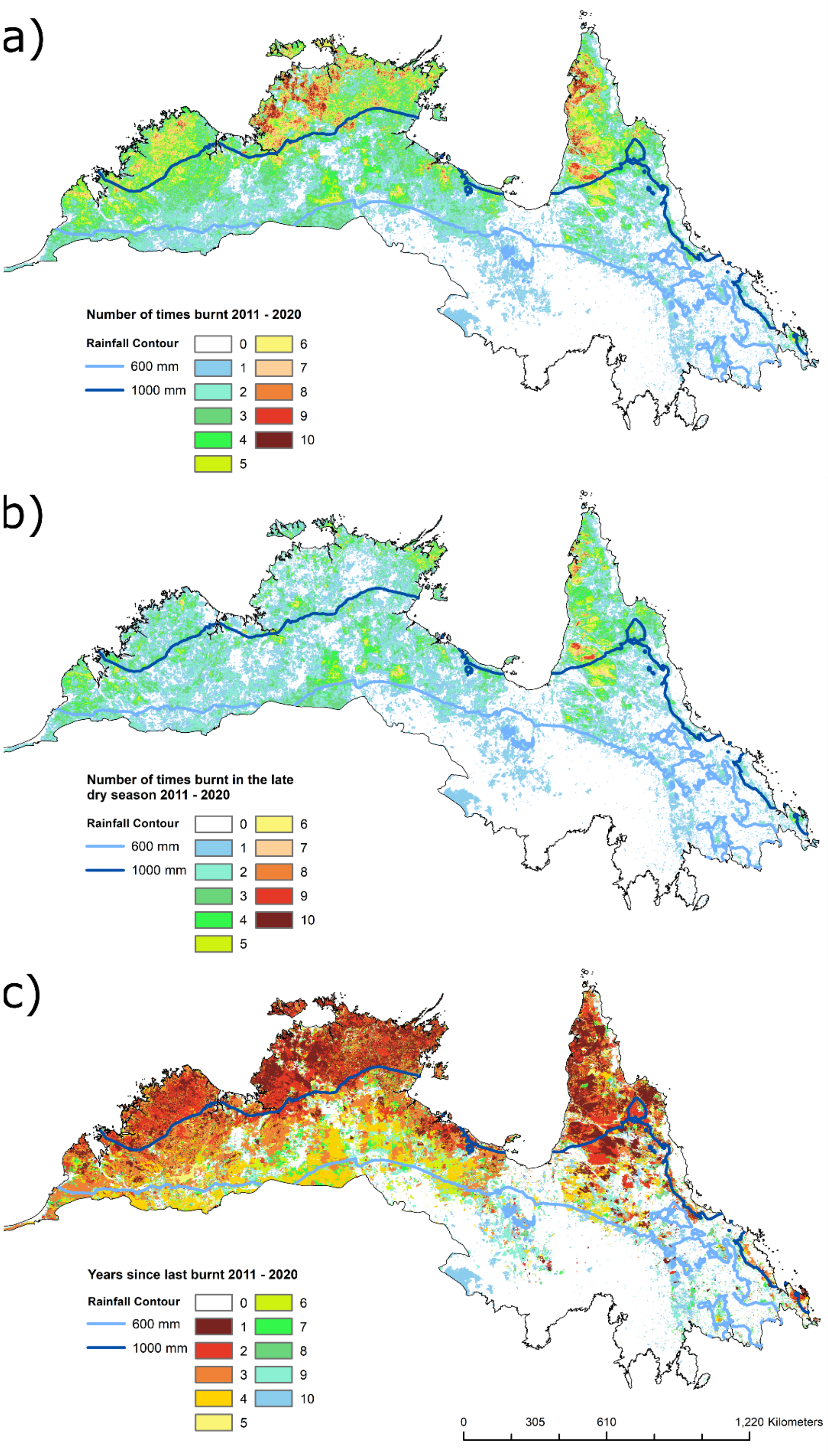


Figure 3.1. Fire frequency and number of years since last burnt within rainfall zones in the northern Australian tropical savanna region. a) Number of times burnt 2011–2020; b) Number of times burnt in late dry season 2011–2020; and c) years since last burnt 2011–2020.

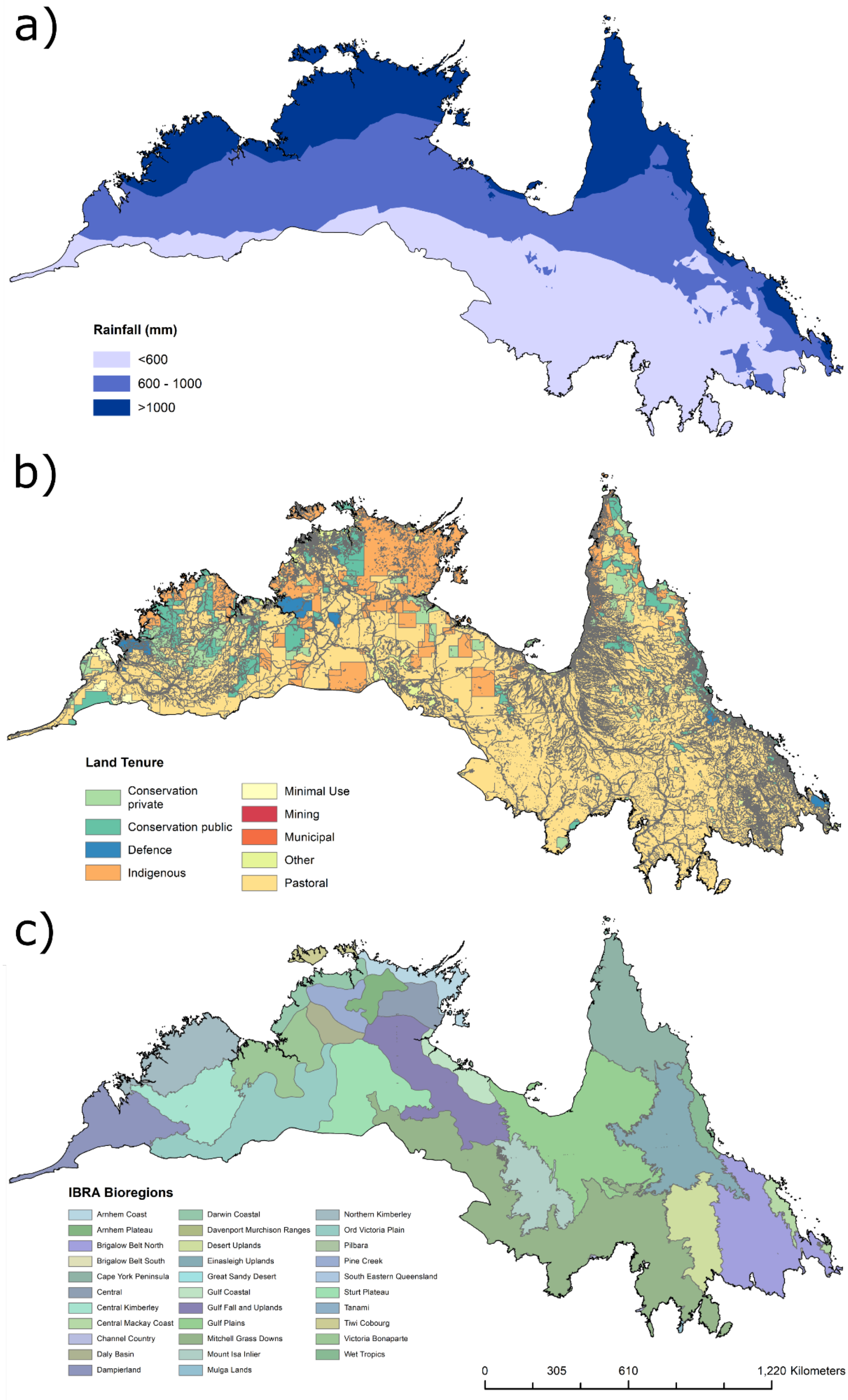


Figure 3.2. Distribution of major climatic, anthropogenic, and ecological systems within the northern Australian tropical savanna region. a) rainfall; b) land tenure; and c) Interim Biogeographic Regionalisation for Australia (IBRA) bioregions.

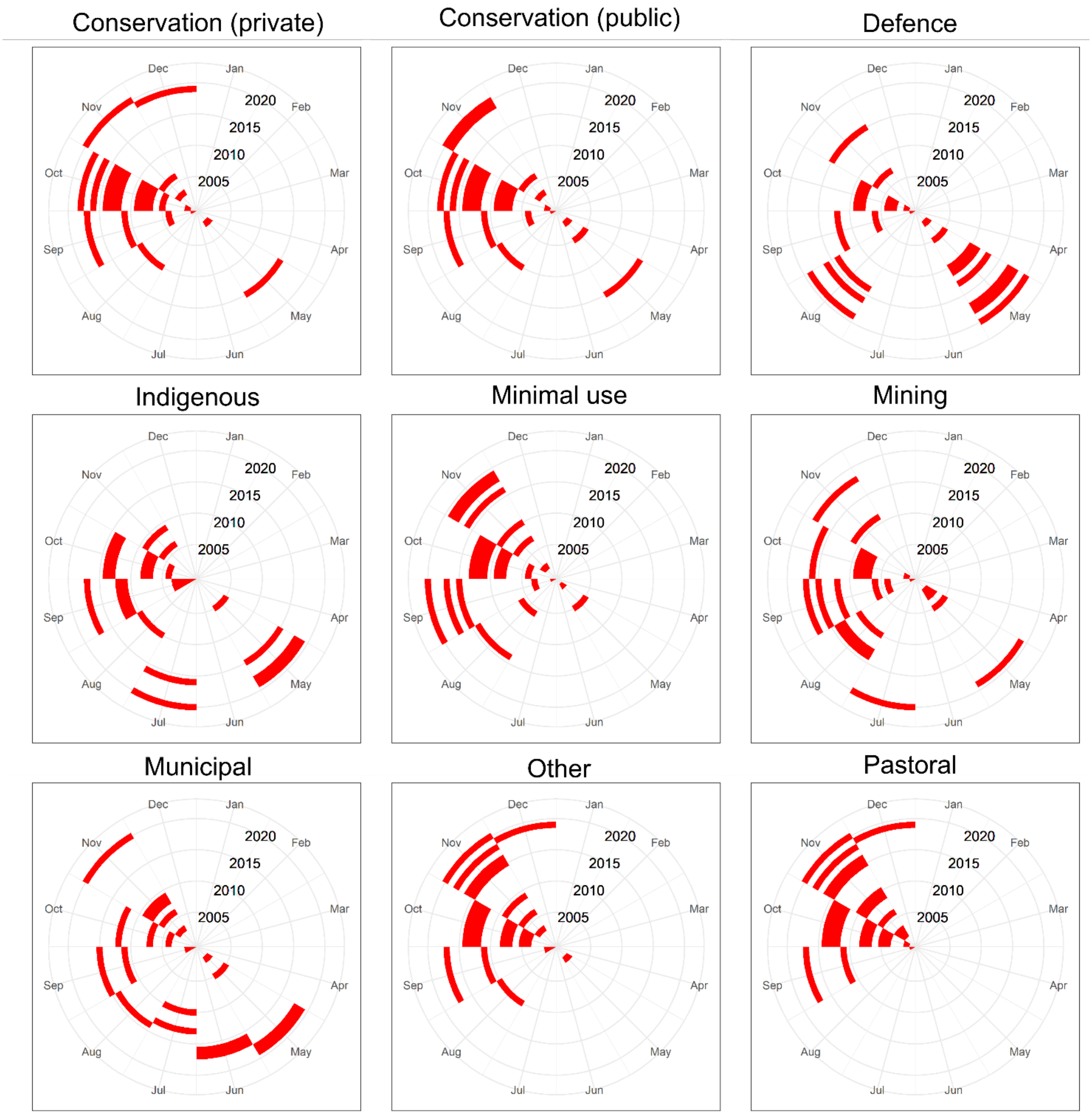


Figure 3.3. The distribution of peak month that fire occurs across different land-tenures within the tropical savanna region of northern Australia. Earliest years are shown in the centre of the plots with later years shown around the outside.

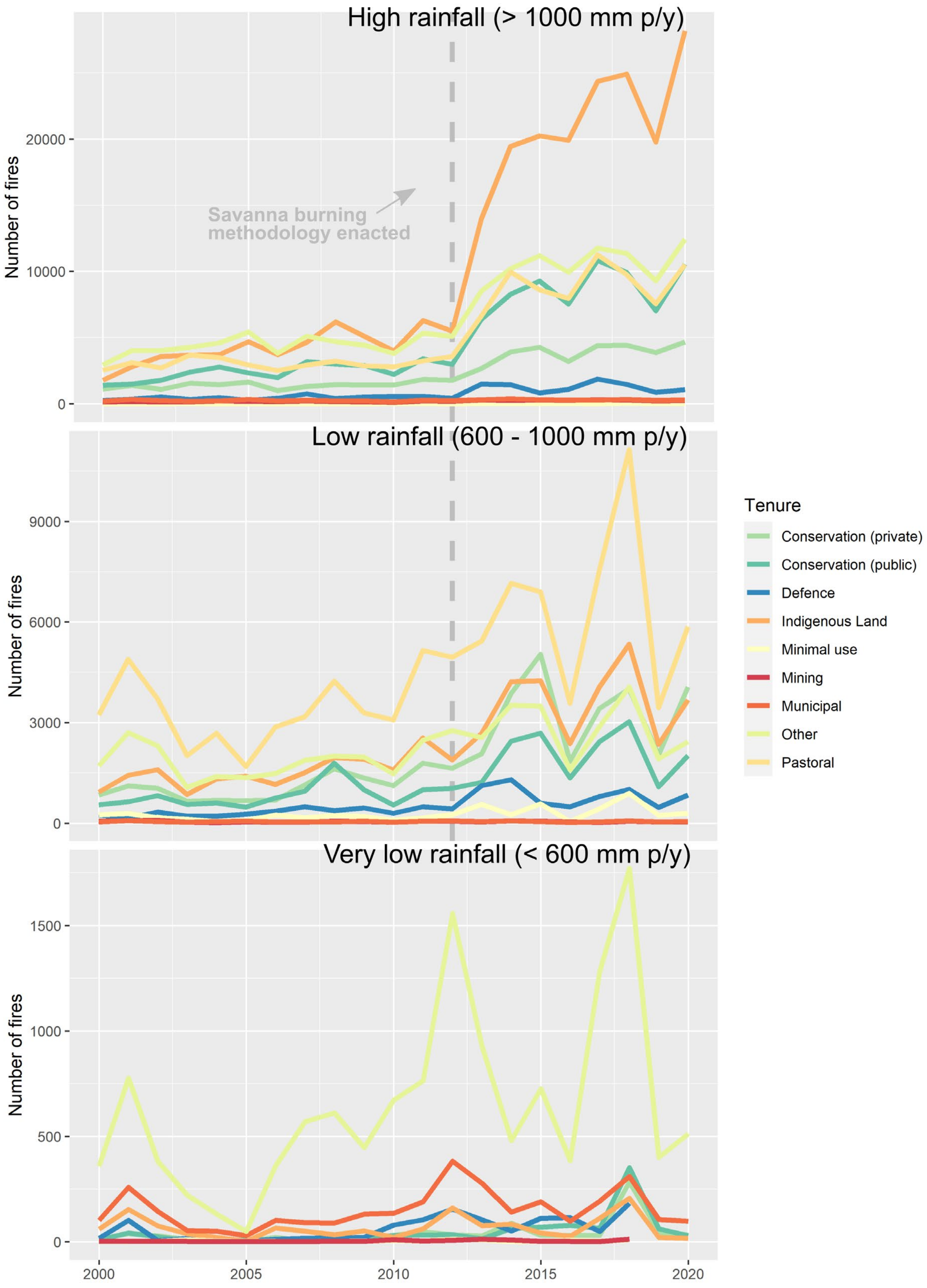


Figure 3.4. Change in the number of early dry-season fires across land tenure types and rainfall zones within tropical savanna in northern Australia. Grey dashed line represents enactment of savanna burning methodology.

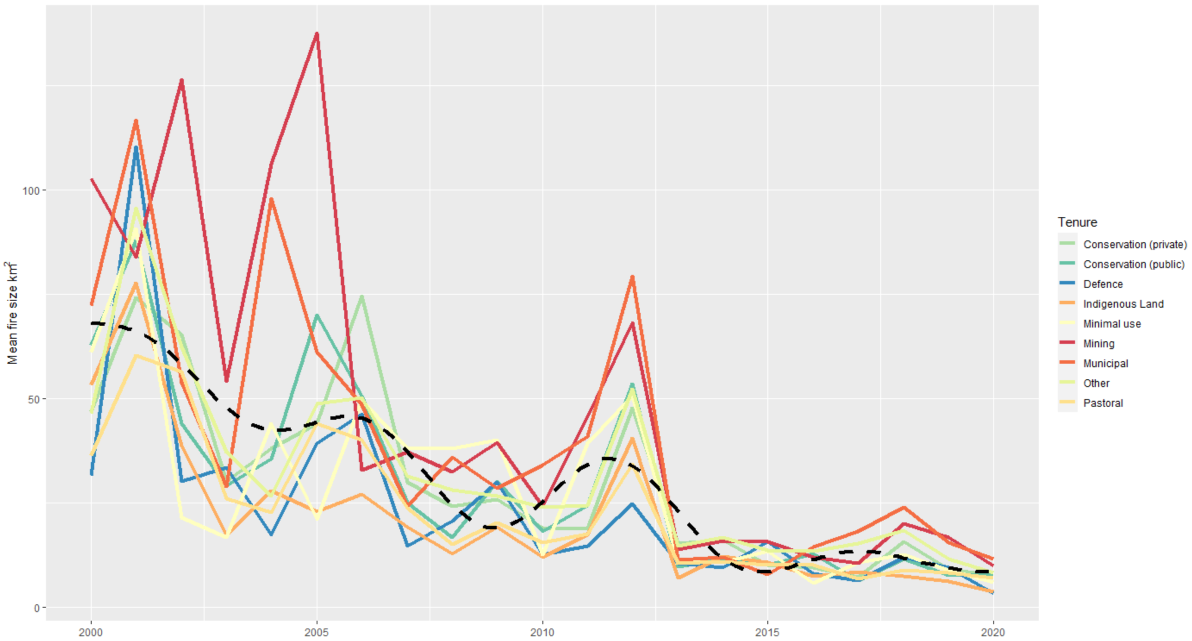


Figure 3.5. Change in mean fire size across land tenure types within tropical savanna in northern Australia. Black dashed line represents average trend across tenures.

4. Synthesise contemporary policy and management influences on savanna burning (i.e. savanna emissions burning methodology)

Within tropical savanna ecosystems, most fires have an anthropogenic origin (Andersen et al. 2012; Yates et al. 2008). Savanna burning has a long history in Australia, with Aboriginal use and management stretching back millennia (Fache and Moizo 2015; Preece 2013). In contemporary times, people burn for a variety of reasons.

- To reduce fuel loads for landscape scale wildfire risk – a practice employed across all tenure types, within the limits of the EPBC Act, which requires federal approval for burning activities that are likely to have a significant impact on nationally protected matter (Commonwealth of Australia 2014)
- To protect life and infrastructure
- To reduce woody growth and encourage green pick to improve agricultural productivity withing pastoral sectors
- To protect biodiversity through the management of invasive species (pests and weeds), and habitat improvement.

By and large, the most instrumental driver of change to savanna burning regimes has been the implementation of carbon farming methodologies.

The relationship between anthropogenic carbon emissions and changes in the earth's climatic systems have been established since the 1990s, with an increasing push since then from various governmental and multinational groups to curb emissions and reduce the likely future impacts to the global system (IPCC 1990). Australia has been a signatory to global climate agreements to reduce greenhouse gas emissions since 1994, when it ratified the United Nations Framework Convention on Climate Change (UNFCCC 1992; Figure 4.1). This global push has helped shape national policy with proposals to create market mechanisms for emissions reduction beginning in 2008, with the Carbon Pollution Reduction Scheme (proposed one year after Australia ratified the Kyoto protocol; Parliament of Australia 2009).

Savanna fires in Australia account for 3% of annual greenhouse gas emissions in Australia (Maraseni et al. 2016). In 2012, the first Kyoto-compliant methodology for the reduction of carbon emissions from savanna fires, via controlled burning regimes, was approved for use under an emissions reduction fund (Commonwealth of Australia 2012). These carbon farming initiatives have progressively been expanded and enhanced to cover more vegetation types and emissions reduction methodologies (i.e. sequestration; Commonwealth of Australia 2015, 2018).

Carbon farming methodologies within this zone promote the change of fire regimes from predominantly late dry-season, intense damaging fires to lower intensity, lower emissions early season fires. This is achieved through the promotion of early season fire, which decreases fuel loads before they can build to destructive levels. The offset in emissions forms the basis of Australian Carbon Credit Units (ACCU) accrued during any defined carbon farming project, which can be traded on the regulated carbon markets. The implementation of carbon farming, and its ability to create a new source of revenue for people managing land in Australian savanna systems, has been one of the largest driving forces for shifts in fire management within this region (Ansell et al. 2019; Edwards et al. 2021; Russell-Smith et al. 2013). Large-scale adoption of this methodology has seen major shifts in fire-management practices (from predominantly unmanaged to heavily managed) across northern Australia, but with particularly enthusiastic adoption by Indigenous owner organisations.

More recently there has been recognition that savanna burning carbon methodologies bring with them a number of assumed co-benefits. Early dry-season fires are considered more benign for wildlife, because they are less intense due to the presence of higher moisture in the vegetation and soils, they occur over smaller areas and tend not to burn the canopies of trees (Russel-Smith et al. 2013). Increased employment and on-Country work opportunities for Indigenous peoples brings added social and economic benefits to some of the most disadvantaged communities in the country. Until recently, these co-benefits have remained unaccounted for, with some buyers of ACCUs choosing to pay a premium for their credits for these assumed co-benefits. In 2019, the Queensland Government introduced the Land Restoration Fund (LRF), a $500 million fund which, alongside facilitating the development of new carbon farming methodologies, has specific aims to support the development of methods accounting for the environmental, economic and social co-benefits of carbon farming methodologies (DES 2020). This program is relatively new and the first projects under the LRF are still ongoing so the impact the program may have on continued fire management within northern Australia is, as yet, unknown.

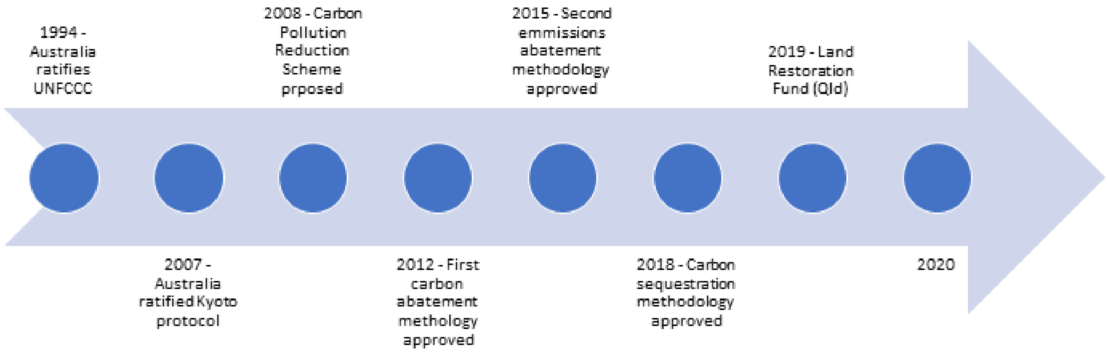


Figure 4.1. Recent timeline of carbon agreements, schemes and methodologies.

5. Provide a summary of existing monitoring methods to define options for designing monitoring programs to demonstrate biodiversity impacts from savanna burning

Savanna ecosystems are shaped by frequent fire events, without which biome shifts and loss of biodiversity can occur. Conversely, intense fire regimes pose an equal risk to savanna biodiversity through negative impacts on soil, water and fire-vulnerable flora and fauna. The effects of savanna burning regimes on biodiversity are driven by a multitude of factors (climate, weather, herbivory, fire history), across spatio-temporal scales (Davies et al. 2021), confounding efforts to quantify relationships between fire-management regimes and ecosystem health. This complexity is compounded by the lack of a long-term, broad-scale biodiversity monitoring methodology framework across the region.

Until recent years, biodiversity monitoring has occurred across relatively small areas of northern Australia, including protected areas managed by federal, state and territory governments, and non-government organisations, such as Bush Heritage and the Australian Wildlife Conservancy (Gillespie et al. 2015). As such, information relating to biodiversity condition throughout the tropical savanna region of northern Australia is lacking. Further, the biodiversity monitoring programs used across the region (Table 5.1) are vast and varied, with no accepted methodology or harmonised approach. While there is consensus that a national, long-term biodiversity monitoring framework that supports evidence-based policy and management decisions is paramount to improved outcomes for conservation, achieving such is complex and unrealised (Likens and Lindenmayer 2011; Lindenmayer et al. 2012; Burns et al. 2018; Eyre et al. 2011; Watson and Novelly 2004). Several of the existing methodologies have potential to be tuned or scaled to demonstrate biodiversity impacts from savanna burning – see examples in Section 5.1, however, none could be used operationally as they stand.

5.1 Existing biodiversity monitoring methodologies

5.1.1 Three Parks Savanna Fire-Effects Plot Network

The Three Parks Savanna Fire-Effects Network, initially established in 1994 to assist with the development of conservation-based fire regimes, combines remote sensing of fires with on-ground assessment of changes in biota through a large series of 220 permanent plots (Russell-Smith et al. 2014, 2010). While this network collects in-depth data on the responses of biodiversity to fire, it currently only covers a small area of Australian savanna systems and lacks the ability to integrate the observed on-ground biodiversity change with broad-scale monitoring of the environment.

5.1.2 Biogeographic modelling Infrastructure for Large-scaled Biodiversity Indicators

Biogeographic modelling Infrastructure for Large-scaled Biodiversity Indicators (BILBI) uses best available biological and environmental data, modelling, informatics, remote-sensing and high-performance computing to assess biodiversity change at fine spatial resolution across the global land surface, further refining mapping of biodiversity patterns in relation to more traditional surrogates such as ecoregions and species range maps (Hoskins et al. 2018).

BILBI is a promising combination of on-ground biodiversity observations with satellite remote sensing to provide estimates of changes in biodiversity across a broad spatial region; however, currently it has not been specifically tuned to estimate biodiversity responses to fire.

5.1.3 Habitat Condition Assessment System

The Habitat Condition Assessment System (HCAS) is a modelling system which combines remotely sensed observations of land cover with reference states that describe the most pristine examples of Australia's native ecosystems in order to estimate changes in habitat condition for all locations across the continent (Williams et al. 2020; Harwood et al. 2016). The HCAS accesses and maps the condition of terrestrial habitats based on their deviation from reference condition – being the most intact examples of native terrestrial ecosystems across contemporary Australia. Habitat condition is scaled between 0.0 and 1.0, with a score of 1.0 indicating that the habitat is in an intact reference state (i.e. it has high levels of ecological integrity) and a score of 0.0 inferring there is no capacity for naturally occurring species to persist (Williams et al. 2020; Harwood et al. 2016). Like BILBI, HCAS shows promise, but currently has not specifically been tuned to fire.

Table 5.1. Existing biodiversity monitoring projects and methodology in the tropical savanna region of northern Australia.

Methodology name	Scale	Region	Flora and fauna	Description	Reference	Website
Accounting for Nature	National			Accounting for Nature utilises reference condition benchmarking to create a common unit of measure (Econd) for building sets of biophysical accounts that can describe the condition of environmental assets (native vegetation, soil, rivers, fauna, etc.) at any scale. Econd, is an index between 0 and 100, where 100 describes an environmental asset in an undegraded state.	(Wentworth Group of Concerned Scientists, 2016)	https://www.accountingfornature.org/wentworth-group
Australian Collaborative Rangelands Information System (ACRIS)	WA, SA, NT, QLD, NSW	Rangelands		ACRIS collates and synthesises monitoring data describing change in the rangelands.	(Day 2007)	https://www.environment.gov.au/system/files/resources/46e443c5-673a-4093-948d-d87830cfc2f9/files/acris-reporting-change.pdf
Australian Wildlife Conservancy (AWC) General fauna and vegetation & key taxa monitoring	QLD, NT, WA		Mammals, reptiles, birds, vegetation, ground characteristics	Plots and targeted sites, some stratified by fire. Primarily annual sampling of mammals, reptiles, birds, and vegetation structure.	(Legge et al. 2008, 2011; Kutt and Gordon 2012)	
Biogeographic modelling Infrastructure for Large-scaled Biodiversity Indicators (BILBI)	Global		Flora and fauna	BILBI uses best available biological and environmental data, modelling and high-performance computing to assess biodiversity change at fine spatial resolution across the global land surface.	(Hoskins et al. 2018)	https://research.csiro.au/macroecologicalmodelling/bilbi/

Methodology name	Scale	Region	Flora and fauna	Description	Reference	Website
BioCondition	QLD	Qld		BioCondition is an assessment framework that measures how well a terrestrial ecosystem is functioning for the maintenance of biodiversity values. It is a site-based, quantitative and repeatable assessment procedure that provides a numeric score along a continuum of 'functional' through to 'dysfunctional' condition. The score is based on a comparison between measurements of specific site-based attributes and a benchmark value for each of those attributes, specific to a particular regional ecosystem. A benchmark value is based on the median value from a range of sites in the reference state, in order to capture inherent natural variability in the attributes.	(Eyre et al. 2015, 2017)	
Habitat Condition Assessment System (HCAS)	National/ global			Remote sensing-based product utilising expert assessed on-ground training sites.	(Harwood et al. 2016)	
Kakadu Monitoring Plots	NT	Kakadu	Flora and fauna	A combination of satellite-based mapping of fire events and on-ground assessment of biota change through a series of 134 permanent plots	(Edwards et al. 2003; Woinarski et al. 2012, 2010)	
Land Condition ABCD Framework				Land Condition ABCD Framework is a measure of health for grazing land that considers its capacity to produce useful forage, ability to infiltrate water, and risk level for soil erosion. The framework assists landholders to understand and manage the physical, biological and chemical elements of soil. The four categories used to identify land condition are A – Good, B – Fair, C – Poor and D – Very Poor	(Karfs et al. 2009)	

Methodology name	Scale	Region	Flora and fauna	Description	Reference	Website
Landscape Conservation Initiative (Department of Environment and Conservation)	WA	North Kimberley	Small mammals, habitat condition	Eighty 0.25 ha monitoring sites sampled to access effects of cattle and fire management on small mammals and habitat condition	(Corey et al. 2013)	
Monitoring, Evaluation and Research (MER) Network pilot (fire and weeds) (CSIRO, TERN)	National		Habitat condition	A 3-year project trialling Australia's first MER network via the implementation of a pilot network aimed at promoting national-scale learning about bushfire recovery across different ecosystem types, and the ecological effectiveness of post-fire interventions. The networks will embed nationally integrated research infrastructure within local ecological restoration programs.	(Commonwealth of Australia 2020)	https://research.csiro.au/biodiversity-knowledge/projects/mer/
North Desert Uplands vertebrate fauna plots (CSIRO)	QLD/ Regional	North Desert Uplands	Vertebrate fauna (mainly birds), woody vegetation and ground cover	Sixty 1-ha eucalypt woodland grazed sites sampling woody vegetation	(Tassicker et al. 2006)	
TERN – AUSPlots (AUSPlots - Rangelands & AUSPlots - Forests)	National			A plot-based surveillance monitoring program, undertaking baseline assessments of ecosystems across the country	(Cleverly et al. 2019)	http://www.ausplots.org/ausplots-program https://www.tern.org.au/news-wabiodiversitymonitoring/
Territory Wildlife Park (CSIRO)	NT/ Regional	Berry Springs	Vegetation/ carbon dynamics	Eighteen 1 ha plots subjected to one of 6 fire regimes accessing fire behaviour and its effects on vegetation, biodiversity and carbon dynamics	(Andersen and Hoffmann 2011; Levick et al. 2019)	

Methodology name	Scale	Region	Flora and fauna	Description	Reference	Website
Three Parks Savanna Fire-Effects Plot Network	NT/ Regional	Kakadu, Litchfield and Nitmiluk National Parks		The Three Parks Savanna Fire-Effects Plot Network extends across three national parks (Kakadu, Litchfield and Nitmiluk) in the Top End of the Northern Territory. The fire monitoring program comprises 2 complementary components: satellite-based mapping of fire events and on-ground assessment of change in biota at a set of permanent plots. Temporal visits are as follows: • 6 months (fire occurrence), • 4 months (fire mapping), • 5 years (vegetation), • opportunistic (fauna). Between 2012 and 2018 the Three Parks Savanna Fire-Effects Plot Network was a member of Long-Term Ecological Research Network (LTERN), Australia, a facility of the Australian Government's Terrestrial Ecosystem Research Network (TERN).	(Russell-Smith et al. 2010, 2014)	https://deims.org/16f934fe-e77d-4769-8baf-c247a3ad3b71
Tiwi Islands Carbon Study (CSIRO)	NT	Tiwi Islands	Fauna and vegetation	Eighteen 50–100 ha plots subjected to one of 3 fire regimes accessing response of vegetation and fauna to fire	(Richards et al. 2012)	

5.2 Towards a broad-scale, long-term monitoring framework to demonstrate the biodiversity impacts from savanna burning

To fully achieve a monitoring system that demonstrates the impacts of savanna burning methodologies on biodiversity, which is extensive (i.e. national), robust and operates at a fit-for-purpose spatial grain, a methodology must:

1. Utilise best available knowledge on the response of biodiversity to fire in savanna ecosystems – this is ideally achieved through intensive field-based monitoring of site through time.
2. Transfer the known responses of biodiversity to fires in savanna ecosystems to areas not directly observed through intensive field monitoring. Field monitoring, while thorough, is expensive and logistically difficult, and carrying out a monitoring program which could sufficiently cover all savanna systems would be logistically challenging. Satellite remote sensing of changes in the earth's surface can provide extensive coverage and potentially fill this gap; however, observations of biodiversity change from space can be challenging, particularly in intact natural systems where ecosystem change is more subtle.
3. Integrate the best available on-ground observations of biodiversity responses to fire with extensive observation of land-cover change from remote sensing. To leverage the strengths of 1) and 2), a modelling system that can translate space-based remote sensing of land-cover change into specific estimates of biodiversity responses to fire would be ideal.

To establish a practical means of continuously assessing biodiversity impact under different fire regimes, it will be important to define functional changes to elements of biodiversity for different fire regimes that include the quantification of critical thresholds where ecological function is altered.

Here we propose a pathway for establishing a hybrid field–modelling approach to biodiversity impact accounting.

1. Conduct a systematic review of literature to establish state of current knowledge for northern Australian savanna ecosystems (implemented in this project)
2. Identify knowledge gaps, spatially and temporally
3. Develop conceptual model of fire impacts in different land types using available knowledge
    a. Use conceptual models, existing research, sampling adequacy and environmental turnover models to identify a monitoring strategy to fill critical knowledge gaps
    b. Establish a list of potential biodiversity metrics that are applicable to northern Australia fire regimes and biodiversity that are aligned with international standards
    c. Identify functional traits of species and ecosystems that are likely to be influenced by altered fire regimes
4. Use conceptual models to define a monitoring framework that will underpin robust accounting for biodiversity change under different fire regimes

5. Use conceptual models to develop a spatial model for assessing biodiversity impact using high-resolution spatio-temporal models of habitat condition contextualised with models of fire-impact thresholds under different fire regimes
    a. Develop workflows to integrate the best available remotely sensed and field-collected biological data-streams into the modelling framework
    b. Use dynamically updating data-streams to develop continuous spatial representations of the inherent state (baseline), current state (currently applied regime) and potential state (desired regime) of local species diversity (alpha diversity), community heterogeneity (beta diversity) and targeted species of significance (e.g. threatened species or species of high local value)
    c. Develop threshold ecosystem states based on historical fire regimes and the response of biodiversity components to establish fire-regime predictors for similar environmental space
    d. Generate indicators of the biodiversity impacts arising from changing fire regimes on any land parcel within the modelling domain
6. Use the modelling framework to produce key accounting metrics for biodiversity:
    a. the expected change in regional diversity (gamma diversity), derived through consideration of both local diversity and spatial heterogeneity in species assemblages (beta diversity)
    b. changes in local diversity (species richness)
    c. impacts on species of significance
    d. areas of biological uniqueness (beta diversity).

6. Summary of ecological expert workshop – Impacts of savanna burning on biodiversity: a review of the evidence – held 16 and 22 October 2020

6.1 Overview

On both 16 and 22 October 2020, a 2-hour virtual workshop was held with ecological experts familiar with savanna burning and biodiversity research in northern Australia. Both workshops covered the same content but had a different set of attendees. The objectives of the workshops were to:

1) Discuss the key findings from a draft of the systematic review of the impact of savanna burning on biodiversity
2) Identify missing data sources
3) Agree on critical knowledge gaps and options to fill these.

The workshops were facilitated by the project team and included 45 experts in total from universities (Charles Darwin University, James Cook University, University of Western Australia, University of Tasmania, University of Queensland), government agencies (Queensland, Western Australia, Northern Territory, federal Department of Agriculture, Water and the Environment), Bush Heritage, Australian Wildlife Conservancy, CSIRO, Tasmanian Land Conservancy and private consultants.

During the workshop, feedback was elicited from experts via breakout groups that were organised according to biological group expertise: vegetation, vertebrates and invertebrates. For further details of the workshop structure, see the agenda in Appendix 4.

6.2 Data sources

A range of data sources, including published literature, reviews, reports and unpublished data were suggested by experts during the workshop as candidates for inclusion in the systematic review. Additional published scientific manuscripts have been included in the review sources where applicable. Table 6.1 lists remaining unpublished datasets and reports.

Table 6.1. Datasets and unpublished reports, recommended by experts during the workshop, that could be used to provide additional information and evidence for the impact of fire regimes on biodiversity in tropical savannas.

Name of source (document, expert)	Who suggested (for follow-up)	Notes
Kimberley fire patchiness, native mammals and population processes – Robyn Shaw	Sam Banks	Unpublished dataset
WA biological surveys with links to fire regimes	Tom Vigilante	Unpublished dataset
Gutta percha burning project (early 2000s) – Mike Nicholas/Tony Grice	Eric Vanderduys	
Possum data – John Winter	Michelle Ibbett	
Recovery plans – Station River, Northern Gulf	Steve Murphy – Indigenous Groups	Report

Name of source (document, expert)	Who suggested (for follow-up)	Notes
	for Golden Shouldered Parrots	
Northern Gulf/Cape York Peninsula Natural Resource Management groups – work in the Northern and Southern Gulf are in reports – Carly Starr	Steve Murphy	Report
Mount Isa region fire reports – Lea Ezzy	Michelle Ibbett	Report
AWC Seven Emu property. Has unpublished data sets for the Gulf Coastal Bioregion – Eridani Mulder	Steve Murphy and Skye Cameron	Unpublished dataset
Sugar bag project Lakefield NP/Laura – Peta Marie Standley	Justin Perry	
Cape York Peninsula Fauna Surveys	Justin Perry	Unpublished reports
Queensland CORVEG database	John Neldner	Dataset
- Manuscript in *Australian Journal of Botany* under review (23 years of observational study focusing on ground layer plants with 5 fires during study period) - Dataset on woody component from the same study (manuscript in prep.) - 300 sites on Cape York that were first visited in 1994 and revisited recently with a 'quick and dirty' assessment of condition, and change in relation to fire regime (but unpublished) - Shoalwater Bay studies	John Neldner	Unpublished datasets
Fire-management guideline documents from ranger groups may have primary data	Alex Kutt	Dataset
Full floristic surveys by NT Government e.g. flora survey of Limmen National Park and pastoral monitoring sites (Rangelands division) e.g. Kidman Springs Research station	Nick Cuff	These datasets provide baseline data for future studies of fire impacts
Monitoring over number of years – foliage projective cover (FPC) sentinel Queensland methods down the rainfall gradient in the Top End – Peter Scarf and Peter Brocklehurst	Nick Cuff	Dataset (terrestrial laser scans)
Work by Mark Andrews in Katherine in 1960s on perennial grasses/vertebrates and fire	Gabriel Crowley	
Debbie Bower's work on amphibians and fire in QLD	Lin Schwartzkopf	
Microbats and fire in Cape York by researchers at James Cook University	Geoff Smith	
Golden-shouldered parrot, Carpentaria grass wren and Black-throated finch recovery plans fall in the relevant region, but still in draft form. BirdLife North Queensland would be a relevant source for an update on these	Gabriel Crowley and Lin Schwartzkopf	Unpublished reports
- Unpublished work on cycads; evidence that fire regime was influential on their persistence in the landscape - 5-year study on sandsheet heath - Potential dataset on Nervillea orchids from Charles Darwin National Park - Mortality rates of woody vegetation in stringybark versus woolybutt communities	David Liddle	Unpublished datasets
- Mary River PhD – has data on fire - Integrated conservation strategy for NT parks including a list of the data that has been collected for the parks	Natalie Rossiter-Rachor	Datasets

6.3 Summary of knowledge gaps and opportunities

Experts were asked to list remaining critical knowledge gaps, in terms of the effect of fire on biodiversity in tropical savannas of northern Australia. These knowledge gaps fell under several broad themes.

1. Understanding the mechanistic pathways, rather than purely phenomenological impacts of fire on biodiversity patterns, either via controlled experiments or through 'natural experiments', which serendipitously use variation in fire across large landscapes. Key areas for further study include soil microbial activity, especially with respect to climate change, soil development, soil chemical processes, erosive processes, and nutrient dynamics; trophic hierarchies and fauna population dynamics; habitat features, such as hollow-bearing trees and coarse woody debris.
2. Understudied biological groups and regions:
    a. invertebrate species (other than ants) e.g. mygalomorph spiders, subterranean invertebrates
    b. Gulf and Cape York regions (and other regions outside of the Darwin coastal area)
    c. reptiles
    d. fungi and lower plants
    e. escarpment country and sandsheet heath
    f. rainforest mosaics, riparian and aquatic ecosystems (both ephemeral and perennial) embedded within savanna landscapes
    g. cryptic species, threatened species and habitat specialists.
3. Measurements and understanding of more nuanced aspects of fire behaviour and fire regime, rather than just an early and late dry-season dichotomy – e.g. specific fire intensity, timing of burns (such as storm burning vs. wet-season burning), pre-fire weather, fire size and patchiness at different scales (within a fire scar vs. landscape-scale).
4. Investigation of both long-term (fire regime) and short-term effects of fires, and immediate vs. delayed effects. This is critical for understanding the effects of climate change on fire regimes and subsequent impacts on biodiversity, as well as tipping points, feedbacks and trajectories of species and communities.
5. Capturing different aspects of biodiversity e.g. genetic diversity, beta diversity (and interconnection with landscape complexity), functional trait diversity (and how traits may be linked to species recovery).
6. Interactive effects between fire and other threats to savanna biodiversity, such as invasive species or grazing by introduced herbivores.
7. How to scale results from single-location, short-term projects to inferences at landscape scales and long time periods, and quantitatively describe uncertainty in findings when applied at these different scales.

Experts also identified several emerging opportunities related to the need for greater understanding and measurement of the impact of fire on savanna biodiversity, including:

1. better descriptions and metrics on how to operationalise specific fire regimes for on-ground implementation
2. an outstanding need to capture, review and integrate other knowledge sources into our understanding of fire impacts on biodiversity e.g. Indigenous knowledge of land management
3. building capability in emerging remote-sensing technologies (coupled with data management systems) that present a good opportunity for the development of detailed fire metrics (in addition to season and frequency) and fuel load changes at landscape scales.

7. Participate in a workshop with key savanna burning stakeholders facilitated by the Department of Agriculture, Water and the Environment

7.1 Background

A workshop with key savanna burning stakeholders was not conducted by the Department of Agriculture, Water and the Environment. CSIRO has contracted NAILSMA to complete this task who partnered with Barry Hunter (Djarnda Enterprises) to conduct a series of individual interviews with key savanna burning stakeholders (Indigenous Carbon Industry Network [ICIN], savanna burning methodology project holders, National Reserve managers in Far North Queensland, private reserve managers and natural resource management groups). Barry Hunter and NAILMSA contacted stakeholders and collated feedback between June and September 2021.This work included targeted discussions with several key savanna burning stakeholders to document the requirements for conducting a detailed multi-sectoral assessment to address concerns and values of the different sectors. There was significant interest in conducting a series of robust workshops to aggregate the views of different fire managers in the context of defining savanna-burning fire regimes that are applied for different values, rather than focusing singularly on the impacts of the savanna burning methodology. The feedback from the meetings with fire-management stakeholders indicated that a far more rigorous and inclusive process was required to adequately address the diverse values of fire managers in northern Australia. Within the budget scope and time frames of this project it was not possible to undertake a rigorous and ethical approach to the planned workshops. Barry Hunter and NAILSMA staff used preliminary feedback from the targeted conversations to establish a questionnaire that was distributed to fire managers in different sectors via an online platform. The responses are presented here.

7.2 Djarnda Enterprises/NAILSMA stakeholder feedback

Author: Barry Hunter

7.2.1 Aims

Identify the different fire regimes and reasons for burning applied in northern Australia under different tenure.

7.2.2 Methods

Unfortunately, COVID-19 restrictions severely affects the ability to gather people. There is particular risk when the target groups consist of possibly vulnerable people from remote communities. It was agreed that the best way to proceed was to conduct online and phone surveys. The designed questions sought to present and acquire understandings of fire practitioners' thoughts and understandings on fire and biodiversity while undertaking savanna burning. This premise was not dependent on burning being undertaken as part of a carbon savanna burning project, but rather any burning activities such as cultural burning, hazard reduction, burning for biodiversity or threatened species and so on.

Target participants

- Indigenous land-management groups (including ICIN, ILSC, NLC)
- pastoralists
- defence
- mining
- reserved lands (public)
- reserved lands (private)
- natural resource management agencies (Cape York NRM)
- other public lands (state agencies responsible for fire management)

7.2.3 Questionnaire preamble

Savanna burning has a long history in Australia, with Aboriginal use and management stretching back for millennia. Across northern Australia, it is a landscape-scale activity that affects vegetation and biodiversity. Many factors affect the frequency and timing of burning including land tenure (e.g. protected areas, pastoral, Indigenous land) and related management objectives (e.g. biodiversity, emissions trading, grazing, weed management, fire prevention). The various fire-management aspirations for Indigenous land have been well described in the literature (e.g. Ansell et al. 2019) and continue to be the focus of discussion at annual north Australia savanna fire forums (savannafireforum.net).

The impact of different fire regimes on biodiversity is of global interest and protecting elements of biodiversity is one of the aims for many savanna fire-management programs. The NESP Northern Australia Environmental Resources Hub funded a project to review the current burning regimes in northern Australia and the existing understanding of their relationship to biodiversity conservation. A secondary aim of the project was to identify pathways and opportunities for monitoring activities and future research which can help to inform how different fire regimes can benefit biodiversity. This project was led by CSIRO in partnership with the NT Government and UWA.

This project included the following activities.

- completed a systematic desktop review of the impacts of fire on biodiversity in savanna landscapes, including compiling evidence that can inform improved long-term fire management
- convened workshops with biodiversity and fire experts to identify critical knowledge gaps, important data sources and refine the systematic review
- described current fire-management regimes on different land tenure types and reviewed their differences and impact on biodiversity
- synthesised contemporary policy and management influences on savanna burning to understand recent trends and changes
- engaged Indigenous organisations to develop a robust and ethical process for capturing the diverse views and experiences of fire managers across northern savanna landscapes.

The key findings of the project so far are:

- There is a significant knowledge gap that encompasses fire and biodiversity in the diverse range of habitat and climatic types across northern Australian savanna landscapes outside the Darwin Coastal Bioregion.
- Previous research has not assessed the mechanisms that are responsible for biodiversity declines.
- Increasing understanding of savanna burning effects on biodiversity will require longitudinal studies that have a consistent experimental design over numerous years, particularly when time scales have to account for species recovery time of vertebrate fauna.
- Addressing critical knowledge gaps will depend on a coordinated and strategic approach across the fire-management and research communities.

Guiding future pathways for understanding savanna burning responses

The current knowledge base for biodiversity responses to fire regimes is concentrated in the Northern Territory, with Queensland and Western Australia having significantly fewer studies. Due to the vast range and variations throughout northern savanna bioregions and subregions, this limits the opportunities and appropriateness of applying NT-based knowledge to other locations.

Seeking to improve understanding of biodiversity responses also provides opportunities to capture, review and integrate other knowledge sources, such as Indigenous knowledge, into existing understanding of using fire for land management. There is also a concurrent opportunity to better describe and create metrics for how to implement specific fire regimes on-ground as well as increasing use of remote sensing technologies to aid the development metrics and improve the database on changing fuel loads across savanna landscapes.

The survey

Through the online survey, we aimed to get a range of feedback from the fire-management sector. The intent of the survey was to present a summary of fire managers' perspectives to guide investment in future research and provide some feedback on the design of future workshops led by the fire-management and research communities. The results are anonymous and are aggregated into broad categories for the report to ensure privacy of the respondents.

7.2.4 Scope of work

- Contact representatives in each of the key participants above and record their interest in participating in a workshop to define the burning regimes of northern Australia and reasons for burning.
- Document the key elements participants want to discuss in a fire-management workshop.
- Create a simple questionnaire to establish a high-level understanding of the interests of different sectors.

  e.g. rank in order of importance the reasons why fire is used on your estate.

  1. Greenhouse gas abatement for carbon credits

2. Protection of biodiversity
3. Protection of infrastructure
4. Protection of forage for livestock
5. Vegetation management, e.g reduce woody thickening or managing weeds.
6. Other (list)

7.2.5 The engagement process

The engagement process was led by Barry Hunter (BH). Key individuals, representatives, and those with engagement in the carbon industry or undertaking cultural burning were targeted. Phone calls and a survey were developed to garner responses from targeted audience. Initial contact with selected interviewees was made by BH. It was important a mix of the identified target audience be asked to provide a response.

7.2.6 Questionnaire

An online questionnaire was developed to capture information from targeted audience.

Questions in the online survey:

1. Would you participate in a savanna burning workshop to discuss methodology, fire-management planning and other issues?
2. What industry group defines you?
3. Please rank in order of importance the reasons why fire is used on your estate.
4. What are the key elements that you would want discussed at a fire forum?
5. What are the other issues you may want to discuss at such a forum?
6. How would you describe what you know about the savanna burning methodology?
7. How likely are you to share your experiences in savanna burning at such a workshop?
8. How would you describe your knowledge of the effect of burning regimes on biodiversity?
9. Are you, or have you been engaged in biodiversity research projects?
10. Are you engaged in research about threatened species?
11. Considering COVID-19 issues, would you participate of workshop was online?
12. What is your gender?
13. What is your age?
14. Are you: (Indigenous/non-Indigenous)

7.2.7 Limitations

Ideally, a face-to-face workshop was the forum to facilitate this type of discussion; however, due to COVID1-9 and the risk of getting people together, the development and distribution of a questionnaire was the only feasible course to gather information. Time was a factor, considering that many of the practitioners are busy in the field undertaking burning and other land-management practices.

7.2.8 Results and discussion

There are specific questions relating to the impact of fire on biodiversity following the rapid uptake of the Emissions Reduction Fund savanna burning methodology. Savanna burning across northern Australia is a major annual landscape-scale activity. Burning frequency and timing is completed for many different reasons that is influenced by land tenure (e.g. protected area, pastoral, Indigenous land) and related management objectives (e.g. biodiversity, emissions trading, grazing, weed management, fire prevention). These objectives have evolved significantly over recent years, with the positive or negative impacts on biodiversity not well understood or monitored.

Seasonal application of fire, fire extent and fire timing has been demonstrated since the commencement and broad-scale uptake of the savanna burning methodology. There is a need for a more nuanced analyses of the effects of annual fires on biodiversity. For this element of the project, we did not seek to comprehensively address the details of fire impacts on biodiversity but make three observations based on our discussion with fire managers. First, appropriate, and rigorous biodiversity monitoring will support better accounting of the environmental impact of savanna burning. Second, such monitoring is expensive and rarely funded by government (Ansell et al 2019). Finally, the sentiments of practitioners have not been adequately addressed and require specific and appropriately funded activities.

Summary of survey responses

See Appendix 5.

- 52% of respondents were from Indigenous land-management groups, 4% from land management agencies or NRM agency, and 40% other (non-specified).
- 66.67% of respondents identified as male and 33.33% female.
- Most respondents were in the 35–44 (33.33%) and 45–54 (33.33%) age groups. 25–34 and 55–64 were the other age groups (16.67% each).
- 24% of respondents identified as Indigenous.
- 76% were non-Indigenous.

In regard to ranking of importance of reasons why fire was used on their estate:

- 42.86% practice of cultural burning.
- 28.57% biodiversity protection.
- 10.53% protection of foraging for livestock.
- 10% greenhouse gas abatement.
- 5.26% vegetation management.
- 5% protection of infrastructure.

Most respondents (96%) indicated a willingness to participate in future fire workshops that addressed impacts of fire upon biodiversity. Other topics of interest included discussion and information on savanna fire methodology and case studies of savanna burning projects (60.87% and 52.17% respectively).

7.3 Review of data availability and willingness of land managers to participate in future monitoring and on-ground adaptive management

Preliminary discussions with fire managers have indicated a willingness to share unpublished data sets and to explore robust monitoring and management methods. However, organisations that had invested in long-term monitoring indicated that they wanted to have a substantive role in progressing methods development and publishing of their existing work. Another key theme from these discussions was that future investment should prioritise projects that collaborate closely with existing long-term fire-management and monitoring projects.

7.4 Identify, prioritise, and scope potential future research and monitoring activities

The summary of critical knowledge gaps and opportunities outlined in Section 6 provides a first cut for an assessment of priorities and scope for potential future research and monitoring. However, due the complexity of this topic and the need to engage a broad group of researchers in expert workshops, we did not explicitly request feedback on the design of future research activities.

Information on research priorities will be prioritised through future fire-manager workshops.

8. Discussion

This study has demonstrated that there are significant knowledge gaps when considering the impact of fire on biodiversity under different fire regimes in northern Australia. There is very little overlap between long-term monitoring sites (which have been published) and savanna-burning projects. There are some prominent examples of long-term systematic surveys in the Northern Territory in the Kakadu and Nitmiluk national parks, which are now the focus of new savanna-burning projects. These will become important sites in the future and should be prioritised for ongoing research. The difficulty of conducting research in the vast, difficult-to-access landscapes of northern Australia, coupled with a small community of practice in this region, has limited research effort to a small fraction of the total environmental space.

Where fire regimes have been tested against elements of biodiversity, such as species richness and abundance, the results are not consistent, and in the most part are not directly comparable due to methodological, habitat, temporal and climatic differences. When considering the impact of late dry-season fire on elements of biodiversity, we found almost equal positive and negative response.

We conclude that the current literature is insufficient to conclude any positive or negative response to commonly applied fire regimes including the regulated savanna burning methodology.

References

ABARES (Australian Bureau of Agricultural and Resource Economics and Sciences) (2021) *Catchment scale land use of Australia - Update December 2020*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, https://doi.org/10.25814/aqjw-rq15.

Andersen AN, Braithwaite RW, Cook GD, Corbett LK, Williams RJ, Douglas, MM, Gill, AM, Setterfield SA and Muller WJ (1998) Fire research for conservation management in tropical savannas: Introducing the Kapalga fire experiment, *Austral Ecology*, 23(2):95-110, https://doi.org/10.1111/j.1442-9993.1998.tb00708.x.

Andersen AN, Cook GD, Corbett LK, Douglas MM, Eager RW, Russell-Smith J, Setterfield SA, Williams RJ and Woinarski JCZ (2005) Fire frequency and biodiversity conservation in Australian tropical savannas: Implications from the Kapalga fire experiment, *Austral Ecology*, 30(2):155-167 https://doi.org/10.1111/j.1442-9993.2005.01441.x.

Andersen AN and Hoffmann BD (2011) Conservation value of low fire frequency in tropical savannas: Ants in monsoonal northern Australia, *Austral Ecology*, 36(5):497-503, https://doi.org/10.1111/j.1442-9993.2010.02151.x.

Andersen AN, Woinarski JCZ and Parr CL (2012) Savanna burning for biodiversity: Fire management for faunal conservation in Australian tropical savannas, *Austral Ecology*, 37(6):658-667, https://doi.org/10.1111/j.1442-9993.2011.02334.x.

Ansell J, Evans J, Rangers A, Rangers AS, Rangers D, Rangers J, Rangers M, Rangers NN, Rangers W, Rangers Y and Rangers YM (2019) Contemporary Aboriginal savanna burning projects in Arnhem Land: a regional description and analysis of the fire management aspirations of Traditional Owners, *International Journal of Wildland Fire*, 29(5):371-385, https://doi.org/10.1071/WF18152.

Australian Bureau of Meteorology (2020) *Average annual rainfall 30-year climatology (1986 to 2015)*, Australian Bureau of Meteorology.

Geoscience Australia (1993) *Australian Land Tenure 1993*. Geoscience Australia, Canberra.

Beringer J, Hutley LB, Abramson D, Arndt SK, Briggs P, Bristow M, Canadell JG, Cernusak LA, Eamus D, Edwards AC, Evans BJ, Fest B, Goergen K, Grover SP, Hacker J, Haverd V, Kanniah K, Livesley SJ, Lynch A, Maier S, Moore C, Raupach M, Russell-Smith J Scheiter S, Tapper NJ and Uotila P (2015) Fire in Australian savannas: From leaf to landscape, *Global Change Biology*, 21(1):62-81, https://doi.org/10.1111/gcb.12686.

Bird DW, Bird RB and Parker CH (2005), Aboriginal burning regimes and hunting strategies in Australia's Western Desert, *Human Ecology,* 33(4:443-464), https://doi.org/10.1007/s10745-005-5155-0.

Bradstock RA, Williams J and Gill MA (2002) *Flammable Australia: The Fire Regimes and Biodiversity of a Continent*, Cambridge University Press.

Brann M (2020) 'Australian Defence Force's prescribed burn on Mount Bundy comes under fire in the Northern Territory', ABC News.

Burns EL, Tennant P, Dickman CR, Gillespie G, Green PT, Hoffmann A, Keith DA, Lindenmayer DB, Metcalfe DJ, Morgan JW, Russell-Smith J and Wardle GM (2018) Making monitoring work: Insights and lessons from Australia's Long Term Ecological Research Network, *Australian Zoologist*, 39(4):755-768, https://doi.org/10.7882/AZ.2018.030.

Cleverly J, Eamus D, Edwards W, Grant M, Grundy MJ, Held A, Karan M, Lowe A J, Prober SM, Sparrow B and Morris B (2019) TERN, Australia's land observatory: Addressing the global challenge of forecasting ecosystem responses to climate variability and change, Environmental Research Letters 14(9):095004. https://doi.org/10.1088/1748-9326/ab33cb.

Commonwealth of Australia (2012) *Carbon Farming (Reduction of Greenhouse Gas Emissions through Early Dry Season Savanna Burning) Methodology Determination 2012*, Attorney-General's Department.

Commonwealth of Australia (2014) *Environment Protection and Biodiversity Conservation Act 1999*, Attorney-General's Department.

Commonwealth of Australia (2015) *Carbon Credits (Carbon Farming Initiative—Emissions Abatement through Savanna Fire Management) Methodology Determination 2015*, Attorney-General's Department.

Commonwealth of Australia (2018) *Carbon Credits (Carbon Farming Initiative—Savanna Fire Management—Sequestration and Emissions Avoidance) Methodology Determination 2018*.

Commonwealth of Australia (2020) *A pilot monitoring, evaluation and research (MER) network*.

Cook GD and Heerdegen RG (2001) Spatial variation in the duration of the rainy season in monsoonal Australia, *International Journal of Climatology*, 21(14):1723-1732, https://doi.org/10.1002/joc.704.

Cooke PM (2009) *Buffalo and tin, baki and Jesus: the creation of a modern wilderness. Culture, Ecology and Economy of Fire Management in North Australian Savannas: Rekindling the Wurrk Tradition*, CSIRO Publishing.

Corey B, Radford I, Carnes K, Hatherley E and Legge S (2013) *North-Kimberley Landscape Conservation Initiative: 2010-2012 Performance Report*.

Davies HF, Visintin C, Gillespie GR, and Murphy BP (2021) Investigating the effects of fire management on savanna biodiversity with grid-based spatially explicit population simulations, *Journal of Applied Ecology*, 58(3):677-686, https://doi.org/10.1111/1365-2664.13801.

Day L (2007) *ACRIS Reporting Change in the rangelands: Status of Biodiversity Monitoring in the Rangelands*.

Department of Agriculture Water and Environment (2020) *Interim Biogeographic Regionalisation for Australia v. 7 (IBRA)* [ESRI shapefile], Department of Agriculture Water and the Environment.

DES (Department of Environment and Science) (2020) *Land Restoration Fund: Priority Investment Plan*, Department of Environment and Science.

Edwards A, Archer R, De Bruyn P, Evans J, Lewis B, Vigilante T, Whyte S and Russell-Smith J (2021) Transforming fire management in northern Australia through successful implementation of savanna burning emissions reductions projects, *Journal of Environmental Management*, 290:112568, https://doi.org/10.1016/j.jenvman.2021.112568.

Edwards A, Kennett R, Price O, Russell-Smith J, Spiers G and Woinarski J (2003) Monitoring the impacts of fire regimes on vegetation in northern Australia: An example from Kakadu National Park, *International Journal of Wildland Fire*, 12(3-4):427-440, https://doi.org/10.1071/wf03031.

Evans J and Russell-Smith J (2020) Delivering effective savanna fire management for defined biodiversity conservation outcomes: an Arnhem Land case study, *International Journal of Wildland Fire*, 29(5):386-400, https://doi.org/10.1071/WF18126.

Eyre TJ, Kelly AL and Neldner VJ (2017) *Method for the Establishment and Survey of Reference Sites for BioCondition*, Version 3,

Eyre TJ, Kelly AL, Wilson VJ, Ferguson BA, Laidlaw DJ and Franks MJ (2015) *BioCondition A Condition Assessment Framework for Terrestrial Biodiversity in Queensland*, Version 2.2.

Eyre TJ, Fisher A, Hunt LP and Kutt AS (2011) Measure it to better manage it: A biodiversity monitoring framework for the Australian rangelands, *Rangeland Journal*, 33(3):239-253, https://doi.org/10.1071/RJ10071.

Fache E and Moizo B (2015) Do burning practices contribute to caring for country? contemporary uses of fire for conservation purposes in indigenous Australia, *Journal of Ethnobiology*, 35(1):163-182, https://doi.org/10.2993/0278-0771-35.1.163.

Gill AM (1975) Fire and the Australian flora: A review, *Australian Forestry*, 38(1):4-25, https://doi.org/10.1080/00049158.1975.10675618.

Gillespie G, Stevens A, Mahney T, Legge S and Choy JL (2015) Integrated monitoring and assessment to support adaptive management and planning. NERP Northern Australia Hub.

Harwood TD, Donohue RJ, Williams KJ, Ferrier S, McVicar TR, Newell G and White M (2016) Habitat Condition Assessment System: a new way to assess the condition of natural habitats for terrestrial biodiversity across whole regions using remote sensing data *Methods in Ecology and Evolution* 7(9):1050-1059, https://doi.org/10.1111/2041-210X.12579.

Hoskins A, Harwood T, Ware C, Williams K, Perry J, Ota N, Croft J, Yeates D, Jetz W, Golebiewski M, Purvis A, Robertson T and Ferrier S (2018) Supporting global biodiversity assessment through high-resolution macroecological modelling: Methodological underpinnings of the BILBI framework, *BioRxiv*, 309377, https://doi.org/10.1101/309377.

IPCC (Intergovernmental Panel on Climate Change) (1990) *IPCC first assessment report*, World Meteorological Organization.

Karfs RA, Abbott BN, Scarth PF and Wallace JF (2009) Land condition monitoring information for Reef catchments: A new era, *Rangeland Journal*, 31(1):69-86, https://doi.org/10.1071/RJ08060.

Kutt A and Gordon IJ (2012) Variation in terrestrial mammal abundance on pastoral and conservation land tenures in north - eastern Australian tropical savannas, *Animal Conservation*, August, https://doi.org/10.1111/j.1469-1795.2012.00530.x.

Legge S, Kennedy MS, Lloyd R, Murphy SA and Fisher A (2011) Rapid recovery of mammal fauna in the central Kimberley, northern Australia, following the removal of introduced herbivores, *Austral Ecology*, 36(7):791-799, https://doi.org/10.1111/j.1442-9993.2010.02218.x.

Legge S, Murphy S, Heathcote J, Flaxman E, Augusteyn J and Crossman M (2008) The short-term effects of an extensive and high-intensity fire on vertebrates in the tropical savannas of the central Kimberley, northern Australia, *Wildlife Research*, 35(1):33-43, https://doi.org/10.1071/WR07016.

Levick SR, Richards AE, Cook GD, Schatz J, Guderle M, Williams RJ, Subedi P, Trumbore SE and Andersen AN (2019) Rapid response of habitat structure and above-ground carbon storage to altered fire regimes in tropical savanna, *Biogeosciences*, 16(7):1493-1503, https://doi.org/10.5194/bg-16-1493-2019.

Likens GE and Lindenmayer DB (2011) A strategic plan for an Australian Long-Term Environmental Monitoring Network, *Austral Ecology*, 36(1):1-8, https://doi.org/10.1111/j.1442-9993.2010.02179.x.

Lindenmayer DB, Gibbons P, Bourke M, Burgman M, Dickman CR, Ferrier S, Fitzsimons J, Freudenberger D, Garnett ST, Groves C, Hobbs RJ, Kingsford RT, Krebs C, Legge S, Lowe AJ, Mclean R, Montambault J, Possingham H, Radford J, … Zerger A (2012). Improving biodiversity monitoring. Austral Ecology, 37(3):285-294, https://doi.org/10.1111/j.1442-9993.2011.02314.x.

Maraseni TN, Reardon-Smith K, Griffiths G and Apan A (2016) Savanna burning methodology for fire management and emissions reduction: A critical review of influencing factors, *Carbon Balance and Management*, 11(1):1-11, https://doi.org/10.1186/s13021-016-0067-4.

McKemey M, Ens E, Rangers YM, Costello O and Reid N (2020) Indigenous knowledge and seasonal calendar inform adaptive savanna burning in northern Australia, *Sustainability (Switzerland)*, 12(3):995, https://doi.org/10.3390/su12030995.

Moritz MA, Batllori E, Bradstock RA, Gill AM, Handmer J, Hessburg PF, Leonard J, McCaffrey S, Odion DC, Schoennagel T and Syphard AD (2014) Learning to coexist with wildfire, Nature, 515(7525):58-66, https://doi.org/10.1038/nature13946.

Parliament of Australia (2009) *Carbon Pollution Reduction Scheme Bull 2009, Explanatory Memorandum (2008-2009),* Parliament of Australia.

Perry JJ, Cook GD, Graham E, Meyer CP, Murphy HT and VanDerWal J (2019) Regional seasonality of fire size and fire weather conditions across Australia's northern savanna, *Int. J. Wildland Fire*, 29(1):1-10, https://doi.org/10.1071/WF19031.

Preece ND (2013) Tangible evidence of historic Australian indigenous savanna management, *Austral Ecology*, 38(3):241-250, https://doi.org/10.1111/j.1442-9993.2012.02415.x.

Queensland Government (2014) *Queensland Spatial Catalogue,* Queensland Government.

Richards AE, Andersen AN, Schatz J, Eager R, Dawes TZ, Hadden K, Scheepers K and Van Der Geest M (2012) Savanna burning, greenhouse gas emissions and indigenous livelihoods: Introducing the Tiwi Carbon Study, *Austral Ecology*, 37(6):712-723, https://doi.org/10.1111/j.1442-9993.2012.02395.x.

Russell-Smith J, Allan G, Thackway R, Rosling T and Smith R (2000) Fire management issues in northern Australia – Fire management and savanna landscapes in northern Australia. Fire and Sustainable Agricultural and Forestry Development in Eastern Indonesia and Northern Australia, *Proceedings*, 91.

Russell-Smith J, Cook GD, Cooke PM, Edwards AC, Lendrum M, Meyer CP and Whitehead PJ (2013) Managing fire regimes in north Australian savannas: Applying Aboriginal approaches to contemporary global problems, *Frontiers in Ecology and the Environment,* 11(SUPPL. 1), https://doi.org/10.1890/120251.

Russell-Smith J, Edwards AC, Sangha KK, Yates CP and Gardener M R (2020) Challenges for prescribed fire management in Australia's fire-prone rangelands-the example of the Northern Territory, *International Journal of Wildland Fire*, 29(5):339-353, https://doi.org/10.1071/WF18127.

Russell-Smith J, Edwards A, Woinarski JCZ, Fisher A, Murphy B, Lawes M, Crase B and Thurgate N (2014) 'North Australian tropical savannas: the Three Parks Savanna Fire-Effects Plot Network', in Lowe A, Lindenmayer D, Burns E and Thurgate N (eds) *Biodiversity and Environmental Change: Monitoring, Challenges and Direction*, CSIRO Publishing.

Russell-Smith J, Edwards AC, Woinarski JCZ, McCartney J, Kerin S, Winderlich S, Murphy BP and Watt F (2010) Fire and biodiversity monitoring for conservation managers: a 10-year assessment of the "Three Parks" (Kakadu, Litchfield and Nitmiluk) Program, *Kakadu National Park Landscape Symposia Series 2007-2009*, 566,(February), https://www.environment.gov.au/science/supervising-scientist/publications/internal-reports/kakadu-national-park-landscape-symposia-series-2007-2009-symposium-3-fire-management.

Russell-Smith J, Yates CP, Whitehead PJ, Smith R, Craig R, Allan GE, Thackway R, Frakes I, Cridland S, Meyer MCP and Gill AM (2007) Bushfires "down under": Patterns and implications of contemporary Australian landscape burning, *International Journal of Wildland Fire*, 16(4):361-377, https://doi.org/10.1071/WF07018.

Tassicker AL, Kutt AS, Vanderduys E and Mangru S (2006) The effects of vegetation structure on the birds in a tropical savanna woodland in north-eastern Australia, *Rangeland Journal*, 28(2):139-152, https://doi.org/10.1071/RJ05029.

UNFCCC (United Nations Framework Convention on Climate Change) (1992) United Nations Framework Convention on Climate Change, adopted 9th May 1992 New York, entered into force 21st March 1994, United Nations Treaty Series vol. 1771, United Nations.

Watson I and Novelly P (2004) Making the biodiversity monitoring system sustainable: Design issues for large-scale monitoring systems, *Austral Ecology*, 29(1):16-30, https://doi.org/10.1111/j.1442-9993.2004.01350.x.

Wentworth Group of Concerned Scientists (2016) *Accounting for Nature*, Wentworth Group.

Williams KJ, Donohue RJ, Harwood TD, Lehmann EA, Lyon P, Ware C, Richards AE, Gallant J, Storey RRJL, Pinner L, Ozolins M, Austin J, White M, Mcvicar TR and Ferrier S (2020) Habitat Condition Assessment System: developing HCAS A revised method for mapping habitat condition across Australia. (December).

Woinarski JCZ, Armstrong M, Brennan K, Fisher A, Griffiths AD, Hill B, Milne DJ, Palmer C, Ward S, Watson M, Winderlich S and Young S (2010) Monitoring indicates rapid and severe decline of native small mammals in Kakadu National Park, northern Australia, *Wildlife Research*, 37(2):116-126, https://doi.org/10.1071/WR09125.

Woinarski JCZ and Braithwaite RW (1990) Conservation foci for Australian birds and mammals, Search, 21(2):65-68, https://publications.csiro.au/rpr/pub?list=BROandpid=procite:110bfb1c-3ce4-4ee3-9672-8aadbb0a4447.

Woinarski JCZ, Fisher A, Armstrong M, Brennan K, Griffiths AD, Hill B, Choy JL, Milne D, Stewart A, Young S, Ward S, Winderlich S and Ziembicki M (2012) Monitoring indicates greater resilience for birds than for mammals in Kakadu National Park, northern Australia, *Wildlife Research*, 39(5):397-407, https://doi.org/10.1071/WR11213.

Woinarski JCZ, Brock C, Fisher A, Milne D and Oliver B (1999) Response of Birds and Reptiles to Fire Regimes on Pastoral Land in the Victoria River District, Northern Territory, *Rangeland J.*, 21(1):24-38, https://doi.org/10.1071/rj9990024.

Woinarski JCZ, Williams RJ, Price O and Rankmore B (2005) Landscapes without boundaries: Wildlife and their environments in northern Australia, *Wildlife Research*, 32(5):377-388, https://doi.org/10.1071/WR03008.

Yates CP, Edwards AC and Russell-Smith J (2008) Big fires and their ecological impacts in Australian savannas: Size and frequency matters, *International Journal of Wildland Fire*, 17(6):768-781, https://doi.org/10.1071/WF07150.

Yibarbuk D, Whitehead PJ, Russell-Smith J, Jackson D, Godjuwa C, Fisher A, Cooke P, Choquenot D and Bowman DMJS (2001) Fire ecology and Aboriginal land management in central Arnhem Land, northern Australia: A tradition of ecosystem management, *Journal of Biogeography*, 28(3):325-343, https://doi.org/10.1046/j.1365-2699.2001.00555.x.

Appendix 1: Draft manuscript (in preparation – link to paper will be included when published)

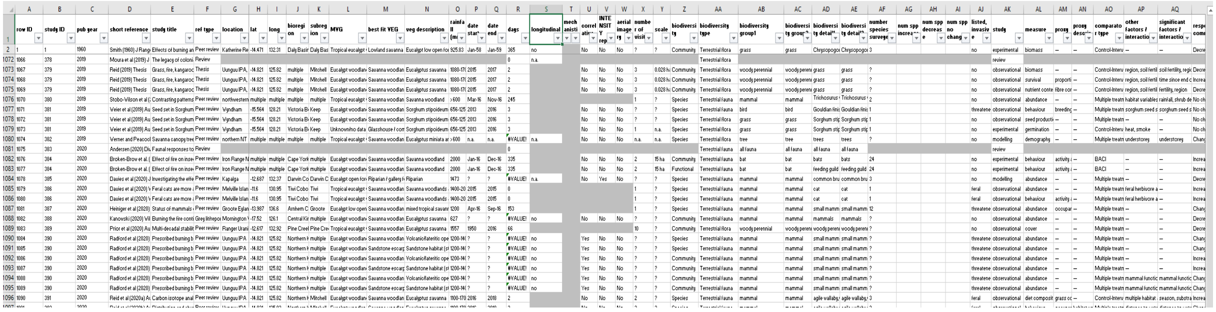
Proposed title: Fire ecology research in Australia's tropical savanna: filling the gaps

John Patykowski, Helen Murphy, Anna Richards, Eric Vanderduys, Ru Somaweera, Michael Douglas, Graeme Gillespie, Justin Perry and others.

Appendix 2: Systematic review spread sheet and PowerBI dashboard

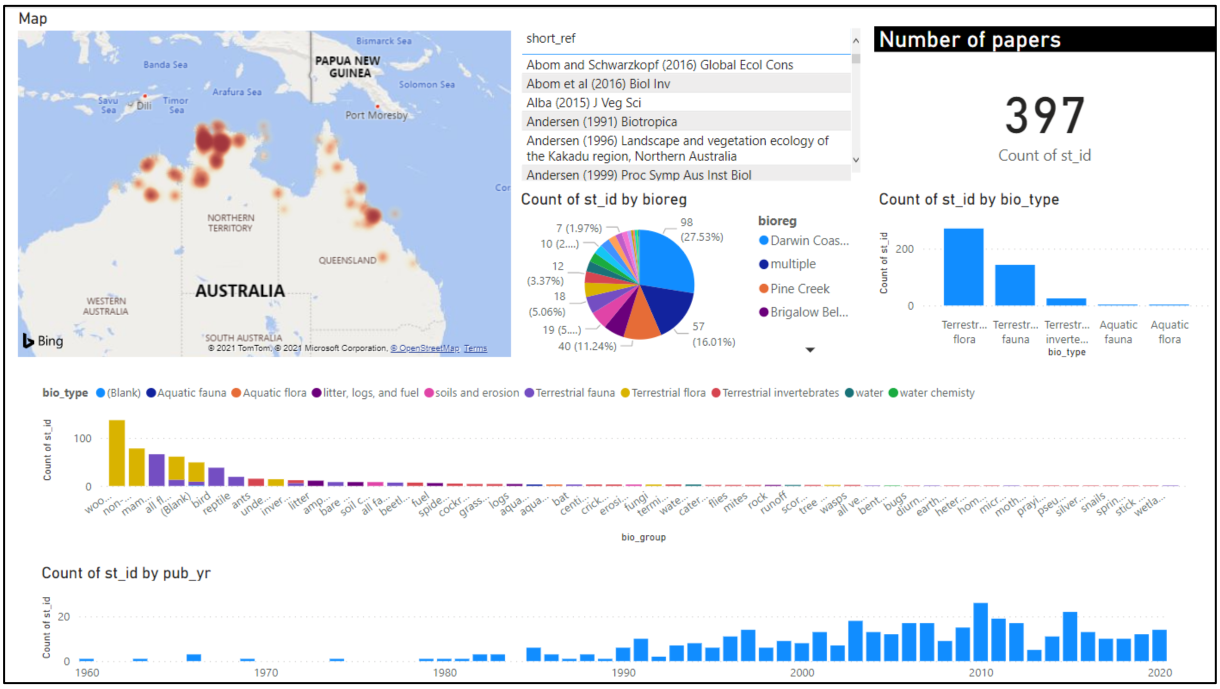
Click on the link below to download the systematic review data base. A final version of the database will be published on the CSIRO Data Access Portal when the publication is submitted.

https://nailsmageneral.blob.core.windows.net/firedata/2021_06_25_sys.review.data.xlsx



Click on the link below to open an interactive dashboard that summarises the key elements of the systematic review database.

https://app.powerbi.com/view?r=eyJrIjoiNDFlNjZjNmQtMzkwMC00MTc1LWI0MjYtNDI2N2EzODBiNTI2IiwidCI6IjJiNzQ1YWMxLTZmNGEtNGUwZS1hOTczLWVkM2YyZjQ3NWUxNyJ9&pageName=ReportSection72783c1b475c03249344



Appendix 3: Summary fire regime data for major land-use types

Peak fire month and mean fire size for each year (2000–2020) across different land-use tenures which fall within the tropical savanna zone within northern Australia – Part A 2000–2010.

Tenure	2000		2001		2002		2003		2004		2005		2006		2007		2008		2009		2010	
	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size
Rainfall < 600mm																						
Conservation (private)	N/A	99.84	Oct	150.7	Nov	14.4	Aug	8.41	Nov	66.22	Nov	5.51	Nov	104.67	Sep	35.9	Oct	7.72	Nov	17.13	Nov	7.48
Conservation (public)	N/A	110.36	Oct	115.61	Nov	9.56	Aug	9.3	Oct	40.75	N/A	0	Nov	73.37	Nov	15.2	Oct	6.2	Nov	51.61	Nov	11.51
Defence	N/A	3.27	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0
Indigenous	N/A	403.25	Sep	489.44	Nov	116.64	Sep	212.1	Oct	807.11	Aug	0.15	Nov	178.2	Sep	362.25	N/A	0	Nov	146.7	Nov	9.11
Minimal Use	N/A	129.89	May	155.33	Nov	13.6	Sep	16.89	Oct	64.48	Oct	6.13	Nov	68.86	Nov	26.47	Oct	17.16	Oct	35.85	Nov	11.67
Mining	N/A	1.55	Oct	825.32	Jan	30.06	Dec	8.05	Dec	4.96	Dec	2.63	Dec	400.32	Nov	15.18	Nov	2.34	Oct	27.21	Dec	12.67
Municipal	N/A	6.85	Oct	208.11	Jul	2.55	N/A	0	Nov	437.93	Oct	3.11	Aug	20.86	Aug	85.11	Nov	11.07	Dec	7.13	Dec	4.84
Other	Sep	43.91	Oct	179.43	Nov	66.17	Sep	21.93	Oct	35.36	Oct	3.83	Nov	56.75	Oct	51.64	Oct	16.82	Nov	25.62	Nov	15.96
Pastoral	Sep	28.59	Oct	98.07	Nov	23.81	Sep	13.25	Oct	26.54	Dec	8.44	Nov	21.75	Oct	34.66	Oct	7.34	Nov	12.09	Nov	9.05
Rainfall 600 - 1000 mm																						
Conservation (private)	N/A	54.99	Oct	78.1	Nov	49.16	Nov	44.51	Sep	54.6	Oct	31.23	Nov	74.41	Oct	28.87	Oct	27.8	Oct	40.23	May	21.11
Conservation (public)	Sep	53.3	Oct	149.42	Nov	60.06	Nov	22.97	Sep	73.97	Oct	33.39	Nov	41.85	Oct	33.35	Oct	23.51	Oct	49.52	Aug	48.37
Defence	N/A	21.24	Oct	59.37	Nov	12.88	Oct	19.21	Oct	13.28	Nov	16.94	Sep	38.19	Nov	11.2	Oct	6.95	Oct	46.07	May	10.18
Indigenous	Sep	57.71	Sep	127.37	Sep	31.79	Sep	31.64	Oct	66.75	Oct	19.64	Nov	41.6	Oct	17.54	Nov	14.5	Nov	18.45	Nov	11.68
Minimal Use	N/A	38.71	May	76.76	May	13.18	Oct	15.4	Nov	42.43	May	16.06	Aug	51.64	Aug	38.33	Oct	43.52	Oct	35.08	Nov	15.79
Mining	Aug	125.86	Oct	82.73	Oct	73.41	May	81.94	Oct	73.84	Oct	35.05	Sep	58.88	Oct	185.13	Oct	85.98	Oct	44.87	Aug	23.36
Municipal	N/A	105.55	Sep	231.26	Oct	57.54	Sep	24.38	Oct	299.63	Oct	63.07	Nov	138.79	Oct	45.03	Nov	53.24	Nov	21.02	May	33.36
Other	Sep	47.53	Sep	161.73	Nov	50.45	Nov	47.28	Oct	67.91	Oct	38.92	Nov	89.12	Oct	33.89	Oct	38.99	Nov	32.91	Nov	25.3
Pastoral	Sep	29.12	Oct	88.99	Nov	48.71	Nov	30.71	Oct	26.82	Oct	21.27	Nov	34.32	Oct	22.54	Oct	19.08	Nov	20.35	Nov	15.49
Rainfall > 1000																						
Conservation (private)	N/A	68.45	Sep	46.65	May	68.71	Nov	29.61	Sep	36.9	May	44.83	Nov	49.27	Oct	53.02	Oct	26.84	Oct	27.92	Aug	21.17
Conservation (public)	Sep	65.66	Oct	62.67	May	54.94	Nov	32.55	Sep	23.68	May	66.53	Nov	30.09	Oct	30.75	Oct	13.47	Oct	22.85	Jun	15.36
Defence	N/A	33.13	Sep	117.62	May	28	Oct	31.8	Nov	11.85	May	42.44	Aug	32.01	Nov	16.3	Oct	12.06	May	26.37	Aug	8.89
Indigenous	Sep	46.88	Sep	41.05	May	42.9	Nov	20.89	Oct	16.35	May	21.99	Sep	20.09	Sep	21.31	Oct	11.52	Oct	27.31	Aug	11.64

Tenure	2000		2001		2002		2003		2004		2005		2006		2007		2008		2009		2010	
	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size
Minimal Use	N/A	3.94	Oct	9.83	Dec	21.45	Oct	6.48	Aug	5.14	Dec	6	Nov	4.57	Nov	4.7	Dec	5.66	Sep	8.69	Jan	4.23
Mining	N/A	47.65	Oct	62.78	May	97.51	May	59.28	Sep	37.27	May	85.75	Sep	32.43	Oct	25.88	Oct	24.66	Oct	28.21	Aug	23.51
Municipal	N/A	39.4	Sep	30.12	May	43.65	Nov	30.58	Oct	46.58	May	43.46	Nov	25.28	Sep	19.88	May	26.75	Oct	31.66	Jul	24.48
Other	N/A	59.48	Sep	58.77	May	67.55	Nov	27.77	Sep	24.52	May	51.1	Nov	29.74	Oct	38.76	Oct	19.12	Oct	27.16	Aug	19.63
Pastoral	N/A	45.56	Sep	38.56	May	49.77	Nov	24.83	Oct	28.34	May	73.78	Nov	37.52	Oct	26.05	Oct	16.66	Oct	23.35	Aug	16.88

Peak fire month and mean fire size for each year (2000–2020) across different land-use tenures which fall within the tropical savanna zone within northern Australia – Part B 2011–2020.

Tenure	2011		2012		2013		2014		2015		2016		2017		2018		2019		2020	
	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size
Rainfall < 600mm																				
Conservation (private)	Oct	11.71	Oct	34.25	Oct	22.28	Aug	13.3	Oct	18.06	Apr	17.55	Nov	21.36	Oct	25.44	Mar	10.65	Aug	2.64
Conservation (public)	Nov	39.55	Oct	31.27	Oct	7.21	Nov	14.97	Oct	11.3	Apr	12.9	Sep	7.87	Oct	23.76	Nov	7.99	Mar	4.48
Defence	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0	N/A	0
Indigenous	Sep	97.39	Sep	30.66	Oct	31.71	Oct	71.64	Nov	69.24	Jan	18.46	Nov	33.31	May	13.33	N/A	0	N/A	0
Minimal Use	Oct	51.98	Oct	53.9	Oct	23.29	Aug	12.86	Oct	11.31	Oct	10.74	Sep	48.74	Nov	19.28	Nov	21.27	Aug	7.78
Mining	Oct	17.55	Nov	37.58	Nov	18.09	Nov	5.36	Nov	2.09	Oct	2.82	Sep	4.92	Nov	2.93	N/A	0	Nov	3.7
Municipal	Sep	85.57	Sep	38.64	Jan	15.25	Jul	3.53	Apr	33.74	Aug	2.55	Nov	3.02	Aug	9.26	N/A	0	Oct	2.93
Other	Sep	20.92	Sep	42.66	Oct	20	Oct	16.11	Nov	12.18	Dec	15.27	Sep	32.46	Nov	24.23	Dec	20.29	Nov	4.94
Pastoral	Sep	14.73	Nov	25.01	Nov	12.65	Nov	9.49	Nov	7.56	Dec	6.36	Sep	8.01	Nov	9.55	Nov	9.31	Nov	4.54
Rainfall 600 - 1000 mm																				
Conservation (private)	Sep	13.73	Oct	58.44	Oct	18.28	Sep	17.43	May	9.75	Oct	9.12	Sep	9.22	Oct	15.47	Dec	10.15	Nov	5.88
Conservation (public)	Sep	37.01	Oct	84.27	Oct	13.12	Oct	14.42	Apr	16.04	Oct	17.76	Sep	12.89	Oct	12.49	Oct	9.5	Nov	11.16
Defence	May	14.19	Sep	31.15	Aug	7.19	Aug	11.38	Nov	18.3	Nov	11.63	May	7.7	May	21.83	Aug	11.98	May	3.21
Indigenous	Sep	17.05	Sep	49.88	Oct	7.62	Sep	12.21	Nov	16.74	Apr	8.04	Sep	17.79	May	9.08	Oct	10.01	Jul	4.52
Minimal Use	Nov	47.53	Sep	36.19	Oct	9.56	Aug	9.53	Sep	18.18	Nov	8.2	Nov	7.65	Oct	5.51	Nov	9.38	Sep	6.61
Mining	Nov	68.91	Sep	80.91	Aug	12.39	Aug	25.08	Sep	51.39	Oct	16.88	Sep	29.89	Sep	27.66	Dec	14.32	Nov	15.13
Municipal	Oct	42.52	Sep	177.62	Sep	7.62	Sep	11.6	Sep	4.61	Oct	19.52	Dec	32.66	Dec	36.94	Dec	21.04	Nov	11.92
Other	Sep	18.8	Oct	70.3	Oct	19.87	Sep	20.37	Nov	18.61	Nov	16.15	Dec	16.17	Nov	27.87	Dec	12.84	Nov	10.26
Pastoral	Sep	11.59	Oct	39.41	Oct	8.81	Oct	9.95	Nov	10.6	Nov	9.66	Dec	7.44	Nov	10.12	Dec	9.24	Nov	5.95
Rainfall > 1000																				
Conservation (private)	Oct	39.15	Nov	29.78	Oct	11.98	Oct	9.89	May	9.1	Nov	9.62	Jun	6.37	May	14.59	Oct	8.22	Nov	8.12

Tenure	2011		2012		2013		2014		2015		2016		2017		2018		2019		2020	
	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size	Peak Fire Month	Mean Fire Size
Conservation (public)	Oct	24.89	May	27.27	Oct	9.87	Oct	5.92	May	8.1	Nov	8.59	Jun	5.62	May	10.01	Nov	7.16	Jul	4.09
Defence	May	13.94	May	17.22	May	10.38	Jun	6.63	Nov	14.88	Aug	6.5	Sep	5.78	Apr	11.76	Sep	11.87	May	4.57
Indigenous	Sep	16.16	Sep	20.24	Oct	5.73	Oct	6.47	Jul	6.04	Jul	5.94	Jun	4.94	May	4.76	Jul	4.7	Jul	3.9
Minimal Use	Sep	11.63	Dec	6.71	Dec	4.22	Dec	2.43	Aug	3.28	Oct	2.04	Dec	2.81	Nov	3.9	Nov	2.8	Nov	4.95
Mining	May	28.08	May	19.92	Jul	7.32	May	8.81	Apr	6.23	Oct	7.19	Jun	7.36	May	21.35	May	19.22	Jul	8.99
Municipal	Aug	39.28	Oct	42.96	Jul	9.39	Aug	10.31	Nov	8.56	Jun	8.72	Jun	6.36	May	11.23	May	14.79	Aug	7.25
Other	Sep	35.16	May	31.44	Oct	11.69	Oct	11.4	May	11.23	Oct	16.72	Jun	9.92	May	14.26	Jul	11.33	Jul	7.64
Pastoral	Oct	35.52	Nov	37.26	Oct	9.83	Oct	7.94	May	11.54	Oct	9.23	Jun	6.08	May	7.77	Dec	9.59	Jul	6.41

Summary of fire regimes by land-use tenure across tropical savanna in northern Australia

Tenure type	Mean Fire Frequency	Mean Late Season Fire Frequency	Mean Time Since Last Burn	Peak Fire Month	Mean fire size km2
Conservation (private)	3.06	1.51	2.83	10	23.48
Conservation (public)	3.35	1.53	2.52	10	18.59
Defence	4.80	1.72	2.28	8	14.62
Indigenous	3.98	1.86	2.71	9	14.02
Minimal Use	2.00	1.51	2.63	10	21.01
Mining	0.76	0.34	1.38	9	32.21
Municipal	0.32	0.12	0.68	9	27.84
Other	1.19	0.62	1.69	10	25.57
Pastoral	1.26	0.88	2.50	10	17.08

Summary of fire regimes by rainfall zone across tropical savanna in northern Australia.

Rainfall Zone	Mean Fire Frequency	Mean Late Season Fire Frequency	Mean Time Since Last Burn	Peak Fire Month	Mean Fire Size km2
< 600 mm p/yr	0.40	0.33	1.83	10	15.29
600 – 1000 mm p/yr	1.95	1.32	3.29	10	22.14
> 1000 mm p/y	3.90	1.77	2.11	9	16.27

Appendix 4: Virtual workshop agenda: Impacts of savanna burning on biodiversity – a review of the evidence

Date: 16 and 22 October 2020

Location: Video conference (WebEx)

Facilitators: Justin Perry (CSIRO), Anna Richards (CSIRO), Helen Murphy (CSIRO), John Patykowski (NT Government), Eric Vanderduys (CSIRO), Ruchira Somaweera (CSIRO), Graeme Gillespie (NT Government)

Objectives:

The National Environmental Science Program (NESP) in collaboration with CSIRO is funding a 1.5-year project to systematically review current savanna burning regimes and their published relationship to changes in biodiversity metrics (including richness, abundance and composition) measured at the level of individuals or functional groups of Northern Australian species. The objective of this workshop is to:

(a) discuss the key findings from a draft systematic review of the impact of savanna burning on biodiversity;

(b) Identify missing data sources;

(c) agree on critical knowledge gaps and options to fill these.

The overall aim of this workshop is to use the collective expertise of the northern Australian ecosystem sciences community to identify information that may inform the review. As part of accepting this invitation we ask that participants agree to the workshop code of conduct.

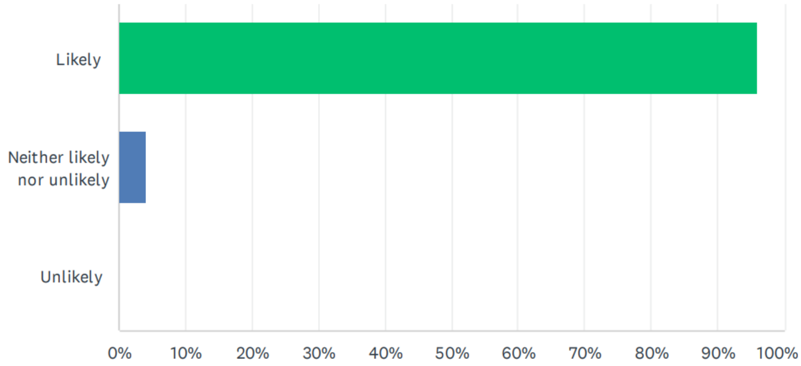
Timetable

Time (AEST)	Item	Facilitated by
10:30 am	Please log in, say a greeting and put yourself on mute	
10:35 am	**Acknowledgement of Country, introduction to project and team, meeting format, video conference tools**	Anna Richards
10:45 am	**Presentation:** The impact of savanna burning on biodiversity: draft findings from a systematic review	Justin Perry
11:05 am	**Questions** (this will be recorded)	Justin Perry
11:10 am	Move into breakout room that you have been assigned: - Vegetation - Vertebrates - General	
11:15 am	**Small group discussion 1** In breakout room discuss: 1. Feedback from systematic review findings 2. Missing data sources (manuscripts, reports)	Helen Murphy, Anna Richards, John Patykowski, Eric Vanderduys, Graeme Gillespie, Ruchira Somaweera
11:40 am	Coffee break	
11:50 am	**Small group discussion 2** Continued from previous session. 1. Key knowledge gaps 2. Opportunities to fill gaps with existing unpublished data or work underway? 3. What are the critical knowledge gaps remaining?	Helen Murphy, Anna Richards, John Patykowski, Eric Vanderduys, Graeme Gillespie, Ruchira Somaweera
12:05 pm	Return to main room	
12:10 pm	**Feedback from small group discussions:** key knowledge gaps	Justin Perry & small-group facilitators
12:25 pm	**Summary and next steps**	Justin Perry

Appendix 5: Survey responses

Q1 Would you participate in a Savanna Burning workshop to discuss methodology, fire management planning and other issues?

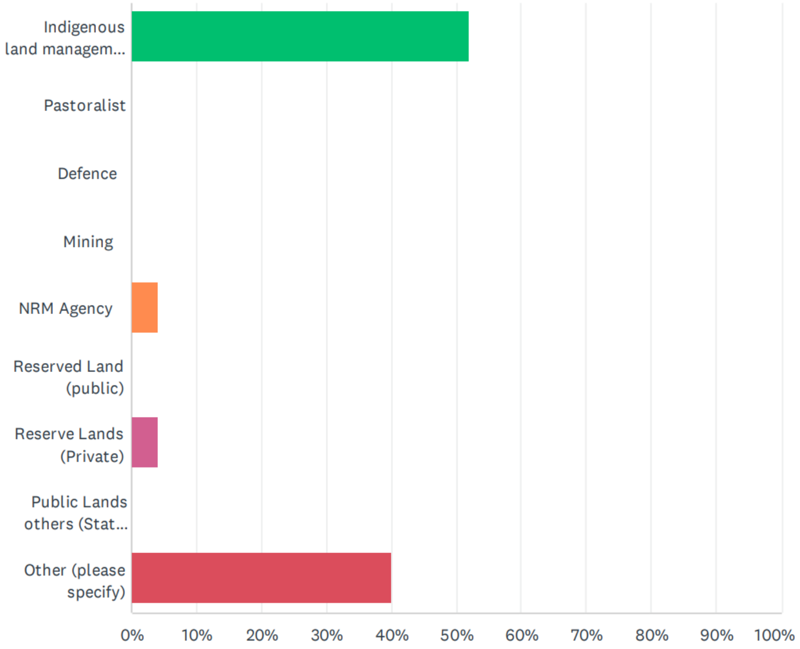
Answered: 25 Skipped: 0



ANSWER CHOICES	RESPONSES	
Likely	96.00%	24
Neither likely nor unlikely	4.00%	1
Unlikely	0.00%	0
TOTAL		25

Q2 What industry group defines you?

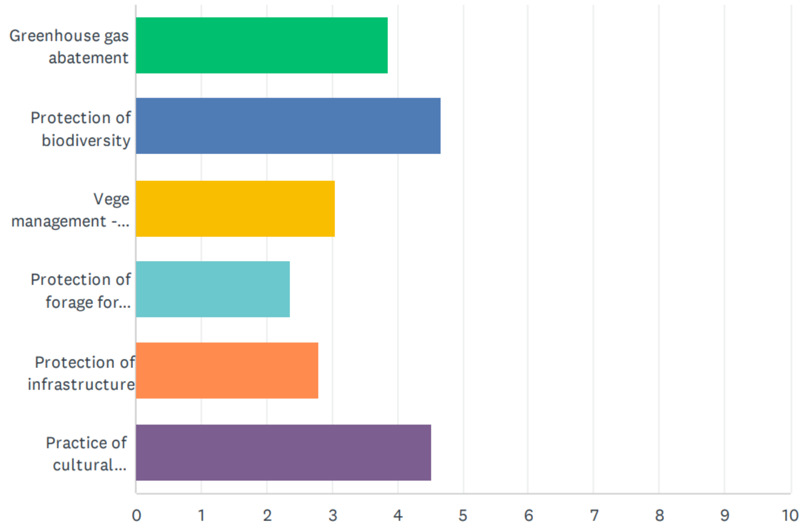
Answered: 25   Skipped: 0



ANSWER CHOICES	RESPONSES	
Indigenous land management group	52.00%	13
Pastoralist	0.00%	0
Defence	0.00%	0
Mining	0.00%	0
NRM Agency	4.00%	1
Reserved Land (public)	0.00%	0
Reserve Lands (Private)	4.00%	1
Public Lands others (State Agency, Rural Fires ...)	0.00%	0
Other (please specify)	40.00%	10
TOTAL		25

Q3 Please rank in order of importance the reasons why fire is used on your estate

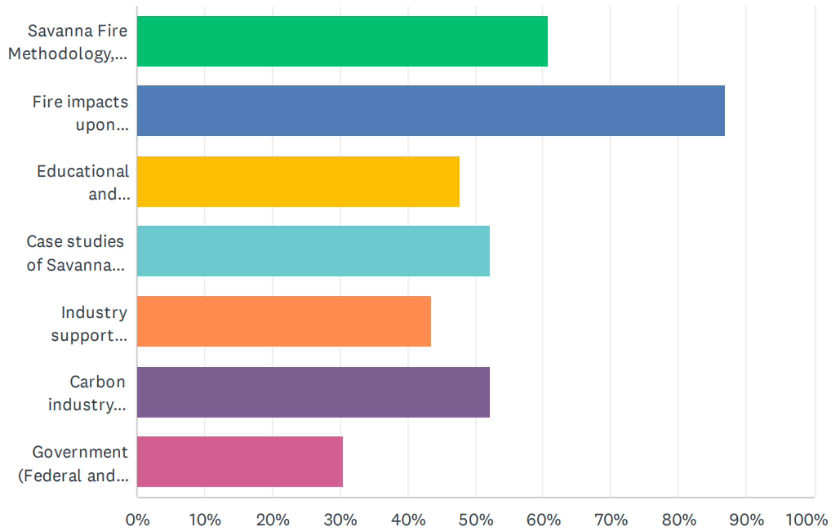
Answered: 21 Skipped: 4



	1	2	3	4	5	6	TOTAL	SCORE
Greenhouse gas abatement	10.00% 2	25.00% 5	35.00% 7	10.00% 2	10.00% 2	10.00% 2	20	3.85
Protection of biodiversity	28.57% 6	42.86% 9	4.76% 1	14.29% 3	9.52% 2	0.00% 0	21	4.67
Vege management - reducing woody thickening	5.26% 1	15.79% 3	21.05% 4	21.05% 4	10.53% 2	26.32% 5	19	3.05
Protection of forage for livestock	10.53% 2	0.00% 0	5.26% 1	10.53% 2	47.37% 9	26.32% 5	19	2.37
Protection of infrastructure	5.00% 1	5.00% 1	20.00% 4	30.00% 6	15.00% 3	25.00% 5	20	2.80
Practice of cultural burning activities	42.86% 9	14.29% 3	19.05% 4	9.52% 2	4.76% 1	9.52% 2	21	4.52

Q4 What are the key elements that you would want discussed at a Fire Forum

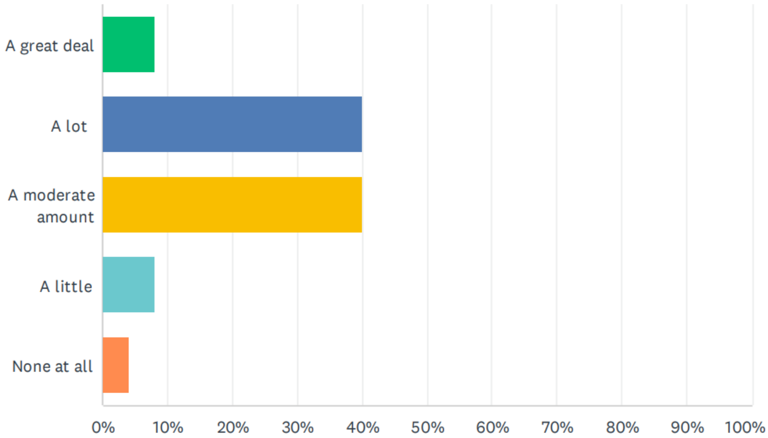
Answered: 23 Skipped: 2



ANSWER CHOICES	RESPONSES	
Savanna Fire Methodology, including fire period?	60.87%	14
Fire impacts upon biodiversity from burning regimes?	86.96%	20
Educational and informational extension support for your fire work on country?	47.83%	11
Case studies of Savanna burning projects from across northern Australia?	52.17%	12
Industry support mechanisms for Savanna burning across northern Australia?	43.48%	10
Carbon industry trends?	52.17%	12
Government (Federal and State/Territory involvement in Savanna burning)	30.43%	7
Total Respondents: 23		

Q6 How would you describe what you know about the Savanna Burning Methodology

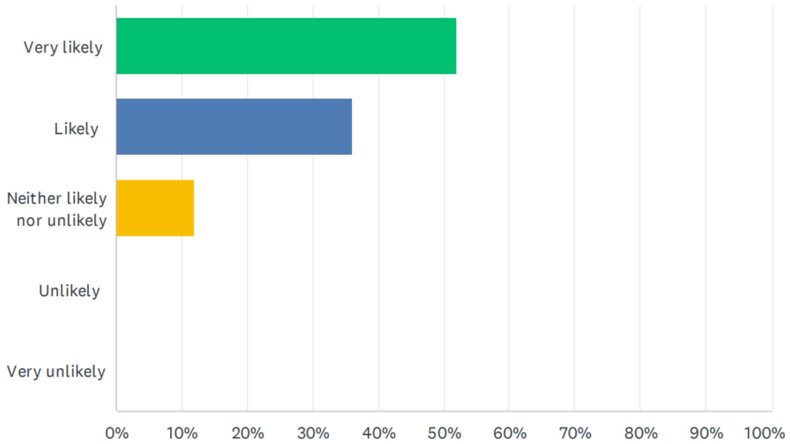
Answered: 25   Skipped: 0



ANSWER CHOICES	RESPONSES	
A great deal	8.00%	2
A lot	40.00%	10
A moderate amount	40.00%	10
A little	8.00%	2
None at all	4.00%	1
TOTAL		25

Q7 How likely are you to share your experiences in savanna burning at such a workshop forum?

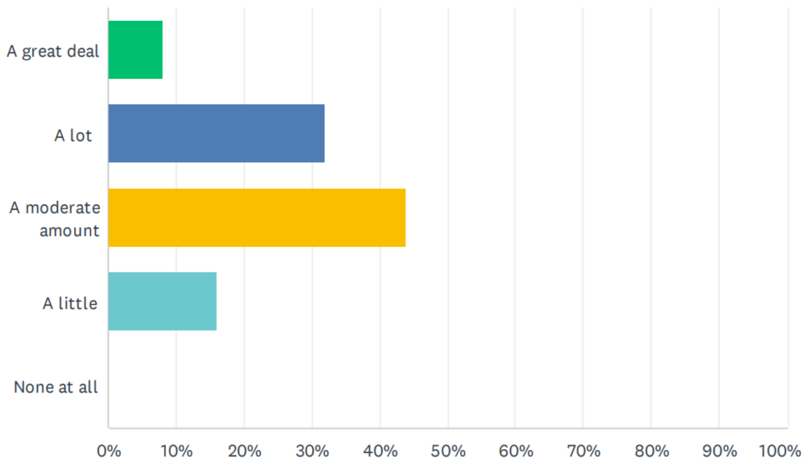
Answered: 25   Skipped: 0



ANSWER CHOICES	RESPONSES	
Very likely	52.00%	13
Likely	36.00%	9
Neither likely nor unlikely	12.00%	3
Unlikely	0.00%	0
Very unlikely	0.00%	0
TOTAL		25

Q8 How would you describe you knowledge of burning regimes upon biodiversity?

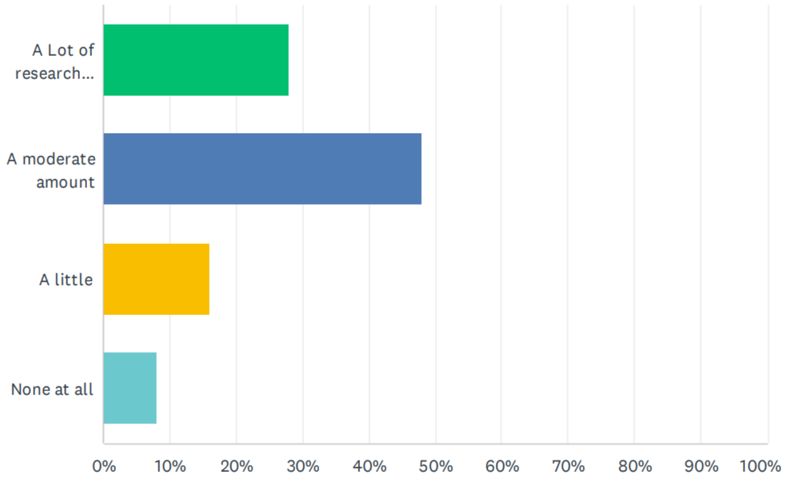
Answered: 25 Skipped: 0



ANSWER CHOICES	RESPONSES	
A great deal	8.00%	2
A lot	32.00%	8
A moderate amount	44.00%	11
A little	16.00%	4
None at all	0.00%	0
TOTAL		25

Q9 Are you, or have you been engaged in Biodiversity research projects

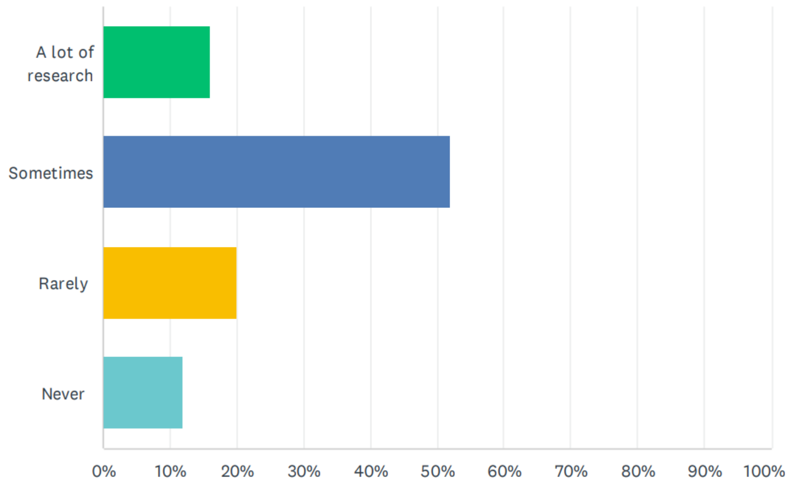
Answered: 25 Skipped: 0



ANSWER CHOICES	RESPONSES	
A Lot of research activities	28.00%	7
A moderate amount	48.00%	12
A little	16.00%	4
None at all	8.00%	2
TOTAL		25

Q10 Are you engaged in research about threatened species?

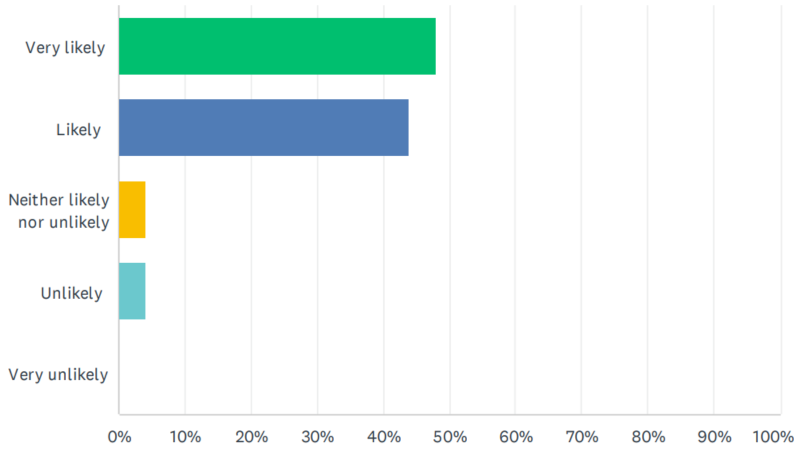
Answered: 25 Skipped: 0



ANSWER CHOICES	RESPONSES	
A lot of research	16.00%	4
Sometimes	52.00%	13
Rarely	20.00%	5
Never	12.00%	3
TOTAL		25

Q11 Considering COVID19 Issues would you participate of workshop was online?

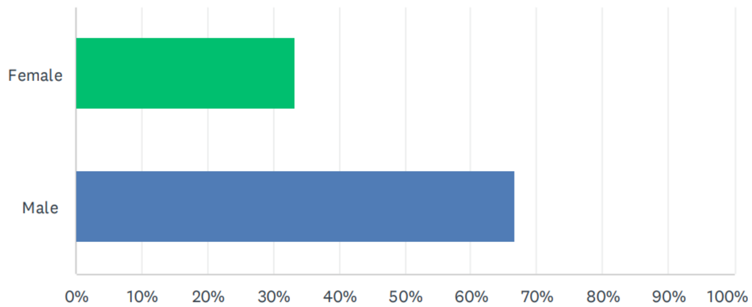
Answered: 25 Skipped: 0



ANSWER CHOICES	RESPONSES	
Very likely	48.00%	12
Likely	44.00%	11
Neither likely nor unlikely	4.00%	1
Unlikely	4.00%	1
Very unlikely	0.00%	0
TOTAL		25

Q12 What is your gender?

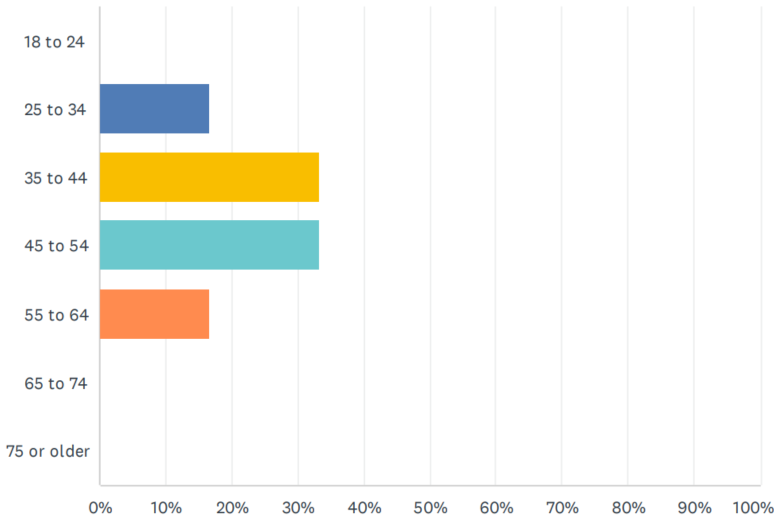
Answered: 24 Skipped: 1



ANSWER CHOICES	RESPONSES	
Female	33.33%	8
Male	66.67%	16
TOTAL		24

Q13 What is your age?

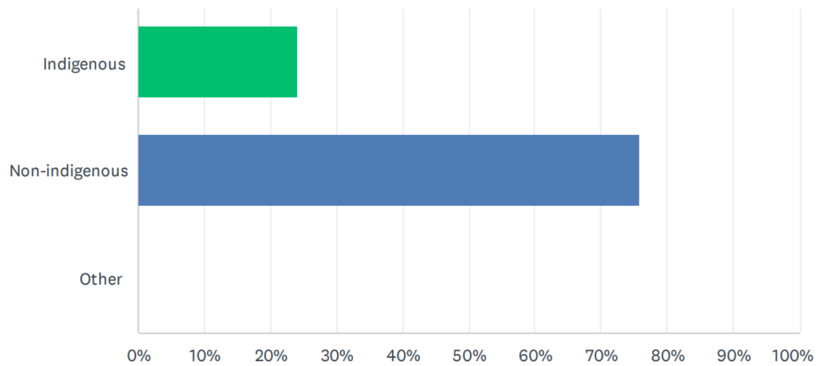
Answered: 24   Skipped: 1



ANSWER CHOICES	RESPONSES	
18 to 24	0.00%	0
25 to 34	16.67%	4
35 to 44	33.33%	8
45 to 54	33.33%	8
55 to 64	16.67%	4
65 to 74	0.00%	0
75 or older	0.00%	0
TOTAL		24

Q14 Are you:

Answered: 25 Skipped: 0



ANSWER CHOICES	RESPONSES	
Indigenous	24.00%	6
Non-indigenous	76.00%	19
Other	0.00%	0
TOTAL		25