Department of Environment and Science

Queensland Parks and Wildlife Service

Planned Burn Guidelines

Introductory volume

Queensland Government

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Disclaimer

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Photos (opposite page):

a. Montane heath, Mount Maroon, Mount Barney National Park. *Photo: Melinda Laidlaw © Qld Govt.*

b. Wetland, northern K'gari (Fraser Island), Great Sandy National Park. *Photo: Rhonda Melzer © Qld Govt.*

c. Northern bettong. *Photo: Adam Creed © Qld Govt.*

d. *Eucalyptus quadricostata* open forest, White Mountains National Park. *Photo: Rhonda Melzer © Qld Govt.*

e. Planned burn, Curtis Island National Park. *Photo: Jack Hargreaves © Qld Govt.*

f. *Triodia longiceps* hummock grassland, Northwest Highlands Bioregion. *Photo: Dan Kelman © Qld Govt.*

g. *Drosera spathulata* post-fire, K'gari (Fraser Island), Great Sandy National Park. *Photo: Rhonda Melzer © Qld Govt.*

h. St Bees Island, South Cumberland Islands National Park. *Photo: Andrew McDougall © Qld Govt.*

Photo (front cover): Planned burn. *Photo: Jack Hargreaves © Qld Govt*

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1 Introduction

1.1 Purpose

The Queensland Parks and Wildlife Service (QPWS) Planned Burn Guidelines—this volume and the guidelines specific to each bioregion (Box 1.1)—provide the foundation for using and managing fire for ecological purposes on QPWS-managed estate (parks and forests).

Fire has an integral role in the evolution and maintenance of Queensland's ecosystems. The considered application of fire to achieve a range of desired outcomes has been practised for many centuries by First Nations people and has greatly influenced current biodiversity. Cultural burning is a form of planned burning. The Department's Gurra Gurra Framework (section 1.3.2) promotes cultural fire management on parks and forests, including for ecological purposes.

QPWS uses planned burning for ecological purposes to achieve biodiversity conservation outcomes, including:

- maintenance of ecosystems and ecological processes across the landscape
- provision of suitable habitat for a diversity of native species
- protection of fire-sensitive communities and species
- conservation of threatened species
- management of weeds and pest animals.

Ongoing planned burning for ecological purposes reduces the likelihood or extent of negative impacts from bushfires on natural and cultural values.

This Introductory Volume presents information about managing fire for ecological purposes, including landscape health, relevant to all bioregions.

It is written for QPWS staff involved in fire management. It provides a clear understanding of the ecological principles underlying burning for conservation in Queensland and how to incorporate these into developing, implementing, and evaluating fire strategies and planned burns and in bushfire response. This volume provides a foundation for:

- planning and implementing ecological burning over time and space
- monitoring and reviewing outcomes to inform future management.

The Introductory Volume is not a fire management manual. It does not address logistic details related to preparing and implementing planned burns and bushfire response. Nor is its purpose to address the fire management requirements and treatments specific to protecting people and infrastructure. However, fire management for ecological purposes contributes significantly to reducing risk across the landscape, supporting other mitigation actions to protect life, culturally sensitive areas and infrastructure from bushfire.

Box 1.1 Bioregional guidelines

Each of Queensland's 13 bioregions has a Bioregional Planned Burn Guideline (referred to collectively as the bioregional guidelines). They provide the ecological basis for QPWS fire management to maintain or recover the good condition of vegetation communities and fauna habitats in parks and forests.

The bioregional guidelines are informed by published information, particularly the *Queensland Herbarium Regional Ecosystem Fire Guidelines*. They also incorporate the knowledge and experience of fire practitioners, including First Nations people.

1.1.1 How to use the Introductory Volume

You can use the Introductory Volume to:

- gain or refresh your understanding of fire ecology and its importance to the effective management of parks and forests and the conservation of ecosystems and species
- prompt curiosity and critical observation of landscapes, ecosystems and species and their response to individual fires and fire regimes
- review the need for integrated management of fire and interacting threatening processes
- consider adaptations to burning practices following major disturbance events and in a changing climate
- challenge practices that may negatively impact ecosystems and species
- inform the development, implementation and review of fire strategies and burn plans.

There are six chapters that explore the ecological principles of burning for conservation in Queensland:

- This first chapter presents background information, including the purpose and scope of the Introductory Volume, the legal, policy and management frameworks for conducting planned burning in parks and forests, and the partnerships that help achieve conservation outcomes and reduce bushfire risk through fire management.
- Chapter 2 discusses the components of a fire regime and its application over space and time.
- Chapter 3 introduces concepts of fire ecology and provides examples of the fire ecology of plant and animal species and interactions between fire and threatening processes. Guiding principles and practices for ecological burning are provided.
- Chapter 4 considers the effects of climate change on fire regimes and biodiversity and an adaptive management response to help conserve ecosystems and species.
- Chapter 5 presents guiding principles for planning, implementing, and evaluating burns for ecological purposes in parks and forests.
- Chapter 6 discusses the impacts of major disturbance events and considers adaptations to fire management.

Eight case studies are included to demonstrate key concepts and outcomes of ecological burning.

This Introductory Volume is not intended to be an exhaustive resource. It aims to prompt thought and encourage further investigation. Where relevant, short lists of additional information sources are provided at the end of subsections.

Additional information

Queensland's bioregions (external)
Bioregional Planned Burn Guidelines (external)
Regional Ecosystem Description Database (external)

Plate 1.1 Fire management is important for the conservation of landscapes, ecosystems, habitats and species:

a. Snappy gum *Eucalyptus leucophloia* low open woodland with a spinifex-dominated ground layer in Boodjamulla National Park. *Rhonda Melzer © Qld Govt.*

b. Flowering *Xanthorrhoea johnsonii*. *Rhonda Melzer © Qld Govt.*

c. Eastern glossy black-cockatoo *Calyptorhynchus lathami lathami*. *Adam Creed © Qld Govt.*

1.2 The legal, policy and management frameworks for conducting planned burning in parks and forests

The safety of the public and their communities is the highest priority in all fire management activities undertaken by QPWS.

The primary responsibility of QPWS is the management of Queensland's parks (national parks, conservation parks and resources reserves) under the *Nature Conservation Act 1992* and forests (forest reserves, state forests and timber reserves) under the *Forestry Act 1959*. The head of power for QPWS to manage fire is through its responsibility to manage the land consistent with the tenure's purpose established under these Acts and the administrative arrangements of the Queensland Government.

QPWS also has obligations under the *Fire and Emergency Services Act 1990* to prepare for and respond to bushfires on the land it manages.

QPWS recognises that substantial environmental changes and landscape modification (e.g. large-scale clearing and fragmentation, timber harvesting, introduction of pest species, urbanisation, agricultural and industrial development), coupled with accumulating impacts of climate change and the dynamic nature of ecosystems, mean that it is not possible, and in some circumstances and for some threatened species may not be desirable, to recreate landscapes to a historic state.

Many flora and fauna species and vegetation communities are dependent on fire for their persistence and health, while some require fire exclusion. In the modern Australian context, most natural areas cannot retain their biological diversity without active ongoing fire management. Maintaining healthy natural ecosystems, and habitats required by their constituent flora and fauna species, including threatened species, is a focus for the use and management of fire for ecological purposes on parks and forests.

To achieve its obligations and responsibilities, all QPWS fire management activities occur within a comprehensive framework (Appendix 1). The strategic direction for these activities on Queensland's parks and forests is outlined in the QPWS Fire Management Strategy 2021–2026, underpinned by the Values-Based Management Framework (section 1.2.1) and Bushfire Risk Management Framework (section 1.2.2) and supported by partnerships (section 1.3).

Additional information

Queensland legislation: https://www.legislation.qld.gov.au/browse/inforce

QPWS Fire Management Strategy (internal)

1.2.1 Values-Based Management Framework

The Values-Based Management Framework (VBMF) is an adaptive management framework that incorporates planning, prioritising, doing, monitoring, evaluating and reporting in all areas of QPWS work (Figure 1.1).

What is the VBMF?

The Values-Based Management Framework (VBMF) is an adaptive management cycle that incorporates **planning**, **prioritising**, **doing**, **monitoring**, **evaluating** & **reporting** into all areas of our business.

We want to keep our parks, forests and reserves healthy by:

- managing and protecting the things that matter most — the key values
- strategically directing management effort towards priorities
- delivering our custodial obligations as a land manager
- setting a level of service for all parks, forests and reserves
- building systems that support adaptive management decision making
- building support through accountability and transparency
- striving for improvement through structured learning and doing

Figure 1.1 Overview of the Values Based Management Framework.

The priority values of a park or forest and the legal, procedural, and moral requirements for managing threats and risks are identified in the planning and prioritisation phases of the cycle (Figures 1.1 and 1.2).

This includes identifying key natural values (e.g. significant ecosystems, species and habitats for which the park or forest is important), the threats to them, their current and desired condition, and the types of management and Levels of Service required to manage these values effectively.

A fire strategy is required for all parks and forests (see Box 1.2). The fire strategy provides directions for fire management, including the maintenance or restoration of priority values and bushfire risk obligations.

The strategic management directions of a fire strategy are typically met through the implementation of a program of planned burns and associated evaluation, learning and adaptation. Objectives for individual burns are identified in the burn plan and evaluated via the burn report. The park or forest's monitoring and research strategy identifies how to evaluate longer-term outcomes. (section 5)

Local knowledge and experience are required to ensure the fire strategy objectives, implementation, and ongoing assessment and monitoring are appropriate to the park or forest.

Box 1.2 Fire strategies

The development and implementation of a fire strategy, including fire management zones (section 1.2.3) are informed by documents including the:

- VBMF planning instruments (values assessments, management plans/statements, other thematic strategies)
- this volume and the relevant bioregional guideline/s
- First Nations' Healthy Country plans (section 1.3.2)
- bushfire risk assessment (section 1.2.2)
- local government bushfire risk mitigation plan.

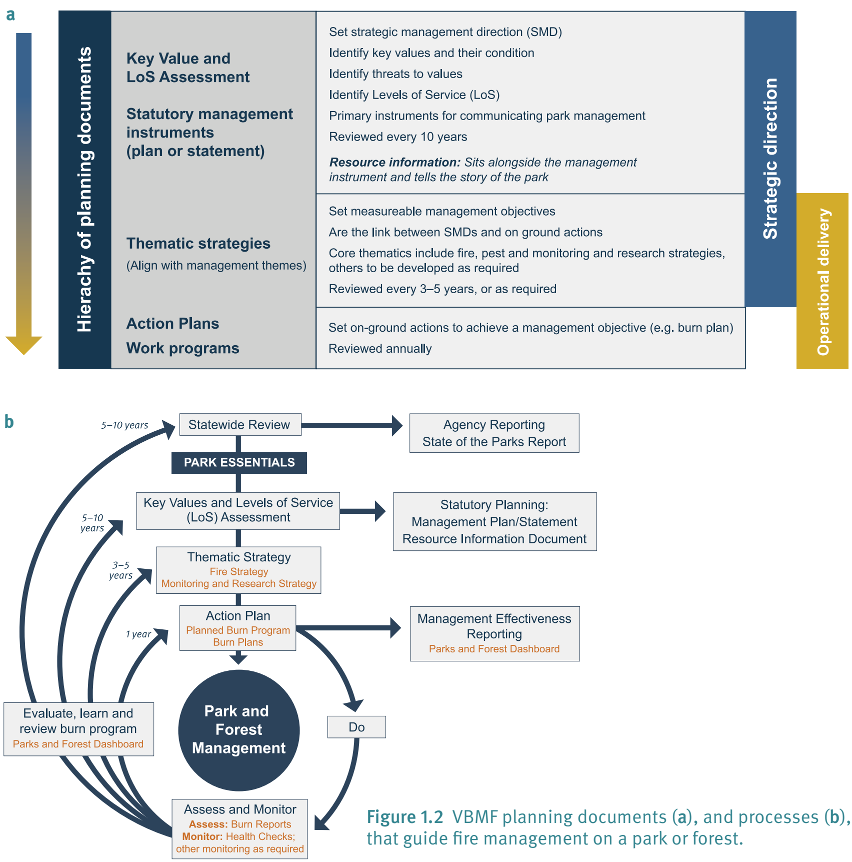

Figure 1.2 VBMF planning documents (**a**), and processes (**b**), that guide fire management on a park or forest.

Additional information

Planning within the Values-Based Management Framework: https://parks.des.qld.gov.au/management/plans-strategies/values-based-framework/planning

First Nations Co-Design Planning Guide (internal)

1.2.2 Bushfire Risk Management Framework

The QPWS Bushfire Risk Management Framework (BRMF) aligns with the *Australian Standard Risk Management – Guidelines* (AS ISO 31000:2018). The BRMF guides the identification, assessment, evaluation and treatment of bushfire risks to the following groups of assets in parks and forests and surrounds:

- non-environmental assets (e.g. human settlement areas, critical infrastructure, industry, heritage buildings/structures)
- agricultural and plantation production
- environmental (natural values) and native timber production values
- cultural and heritage values.

Risk assessments should be conducted for all parks and forests and assets within 100m of the park or forest.

Risk assessments should be done during the development or review of the fire strategy to inform strategic management directions and associated actions, including implementing planned burns. Risk assessments should be reviewed regularly according to the Levels of Service (section 1.2.1).

Queensland Fire and Emergency Services (QFES) considers risk similarly in their bushfire mitigation programs. These programs incorporate mitigation activities and community engagement and education programs. QFES risk mitigation programs assess risk at the local government area scale with the annual review of bushfire mitigation plans.

The principles of risk management outlined in the Australian standard (AS ISO 31000:2018) are embedded in QPWS fire management actions and processes.

Additional information

QPWS Bushfire Risk Management Framework (internal)

QFES Program Grasstree and Operation Sesbania: https://www.qfes.qld.gov.au/prepare/bushfire/program-grasstree

AS ISO 31000:2018 (external)

1.2.3 Fire management zones

QPWS uses fire management zones to spatially define the principal purpose/s of fire management for each part of a park or forest. Each fire management zone contributes to reducing the potential for negative impacts from bushfire, regardless of the principal purpose of the zone.

The cumulative benefits of managing the landscape with fire across all zones include not having to rely on 'sacrificial areas' to mitigate bushfire impacts.

The effective management of protection zones and bushfire mitigation zones promotes community confidence and enables greater flexibility in using a diversity of fire for ecological purposes across the broader landscape.

> “It is desirable that most fire management zones contribute in some way to both mitigation of unplanned fire and biodiversity conservation, even though this often involves more complex planning than the simpler approach of zones with (primarily) a single purpose. When all zones are considered complementary, greater recognition is given to the cumulative benefits of management of each zone (across a landscape) with less reliance on the traditional ‘sacrificial area’ to mitigate fire effects on assets.” Rose et al. (1999)

Not all zones are required in all parks and forests. The key ones are briefly described below.

Protection zone

In a protection zone, fuel is reduced as often as necessary to provide a high level of protection to an asset.

The intent of a protection zone is to substantially reduce the intensity, flame height and rate of spread of a bushfire, minimising the risk of crown fires and ember attack, and increasing the likelihood of controlling the fire.

Protection zones are typically the most intensively and frequently treated zones, with fuels managed to a low to moderate overall fuel hazard and fuel load. Fuel may be managed by various means, including planned burning and mechanical and chemical treatment.

Natural values remain important in protection zones. These zones provide habitat for some native species, particularly those that prefer or persist in regularly disturbed situations or that do not require an understorey. For example, if a tree layer is retained, species such as the koala *Phascolarctos cinereus* may use the zone.

The characteristics of the area (e.g. topography, vegetation, fuel type) and conditions (e.g. soil moisture, seasonal conditions, weather) must be considered when conducting planned burns in the zone. This will minimise negative ecological outcomes, such as loss of old-growth trees, or perverse outcomes, such as increased fuel loads due to high biomass weed invasion or increased woody regrowth. The latter can result when burning in dry conditions and increases the complexity of managing the zone for its intended purpose.

Bushfire mitigation zone

Bushfire mitigation zones (previously known as wildfire mitigation zones) are strategically important areas of fire-adapted ecosystems in a park or forest. These zones are managed to reduce the potential of bushfire to threaten at-risk assets, but with the primary intent to help conserve biodiversity.

Fuel loads in a bushfire mitigation zone are managed by planned burning. These zones are managed in a similar way to a land management zone. The planned fire parameters are consistent with the ecological requirements of the vegetation communities. However, in a bushfire mitigation zone, fire frequency is at the shorter end of the range acceptable for the ecological requirements of the vegetation communities.

The aim is usually to create a mosaic of burn ages rather than a uniform age-class. However, continuity of fuel-reduced areas is required to reduce the movement and complexity of a bushfire where fire has the greatest potential to move through the landscape.

Land management zone

The purpose of fire management in this zone is to restore or maintain the natural role of fire as an ecological process in fire-adapted ecosystems. Conservation of biodiversity is the primary focus of this zone. However, fire management in this zone complements the objectives of other zones, not least because achieving conservation outcomes requires reducing the risk of negative impacts from bushfires.

Plate 1.2 Sand dunes dominated by sandhill cane grass *Zygochloa paradoxa* and hard spinifex *Triodia basedowii* open grassland, with Georgina gidgee *Acacia georginae* low open woodland in the swale. The recommended strategy for the swale community is to exclude fire by reducing fuel in adjacent vegetation communities where possible or undertake partial burns when necessary to reduce fuel loads and protect against severe bushfire. Simpson Desert.

Photo: © Harry Hines.

Exclusion zone

The intent of the zone is to exclude fire from fire-sensitive ecosystems, such as rainforests, mangroves, coastal foredune communities and some Acacia-dominated communities (e.g. gidgee *Acacia cambagei*, blackwood *Acacia argyrodendron*). These ecosystems are not adapted to fire and do not require fire to maintain their structure, function or composition.

Fire exclusion is critical for some cultural sites, such as rock art complexes and associated vegetation. These sites are generally included in an exclusion zone, with adjacent protection in the form of a fire line and/or a bushfire mitigation zone.

Many fire-sensitive communities are largely self-protecting, particularly during planned burn conditions. Their structure and microclimate and/or position in the landscape (e.g. on rocky outcrops or in moist gullies) may mean that they require minimal fire management to protect them. However, some of these communities are under increasing threat from fire due to climate change and/or ecosystem-changing weeds. These include high-biomass grasses, such as buffel grass *Cenchrus ciliaris* and shrubs, such as lantana *Lantana camara* and Siam weed *Chromolaena odorata*.

Fire exclusion requires:

- clearly identifying exclusion zones on fire maps
- ensuring adequate protections are in place before conducting planned burns nearby
- directing resources to protect exclusion zones during bushfires (where possible).

Protecting an exclusion zone from bushfire is often best achieved by conducting planned burns in surrounding fire-adapted vegetation when conditions are favourable.

Exclusion zones should be clearly identified on fire maps for planned fire and bushfire response.

Additional information

DERM 2012, *QPWS Planned Burn Guidelines: how to assess if your burn is ready to go* (internal)

Hines et al. 2010, *Overall Fuel Hazard Assessment Guide*. (external)

Rose et al. 1999, 'The importance and application of spatial patterns in the management of fire regimes for the protection of life and property and the conservation of biodiversity', in *Proceedings of the Australian Bushfire Conference – Bushfire '99*.

1.3 Achieving conservation outcomes and risk reduction through shared responsibility

QPWS has an important role to play in the management of fire in Queensland, including bushfire. QPWS supports and encourages collaboration between responsible parties and pursues partnerships to formalise shared goals in line with the Queensland Bushfire Plan (section 1.3.1).

QPWS recognises that fire needs to be managed across the landscape in partnership with First Nations people (section 1.3.2) and through collaboration with other agencies, such as QFES, occupiers and users of parks and forests and neighbours (section 1.3.3).

A range of QPWS activities helps reduce the likelihood and consequence of bushfire. By maintaining a planned burn program for ecological purposes across parks and forests, QPWS makes a significant contribution to bushfire risk reduction. This program reduces the negative impacts of bushfires, limiting their occurrence, extent, severity, duration and the resourcing required to contain them. Where cross-tenure fire management occurs, the benefits are multiplied.

1.3.1 Queensland Bushfire Plan and Bushfire Management Groups

QFES is the primary agency for bushfire management in Queensland under the Fire and *Emergency Services Act 1990*, Queensland State Disaster Management Plan and Queensland Bushfire Plan (QBP).

The QBP enables bushfire hazard to be managed through prevention, preparedness, response and recovery across tenures. QPWS is committed to involvement at all levels of the bushfire management structure outlined in the QBP. The Department of Environment and Science (DES) and QFES have an interagency protocol for fire management. The protocol establishes arrangements that promote collaboration to enhance the effectiveness of fire management in Queensland.

Collaboration between QPWS, QFES and other organisations involved in fire management is enabled through Bushfire Management Groups established under the QBP. These include Locality Specific Fire Management Groups (LSFMG) and Area Fire Management Groups (AFMG).

While the bioregional guidelines provide the ecological basis for fire management in parks and forests, they are also a valuable resource for AFMGs and LSFMGs.

Additional information

QPWS Bushfire Risk Management Framework (internal)

QFES Queensland Bushfire Plan: https://www.disaster.qld.gov.au/cdmp/Documents/QLD-Bushfire-Plan.pdf

QFES and QPWS Interagency Protocol for Fire Management (internal)

1.3.2 First Nations peoples

QPWS acknowledges First Nations peoples' management of fire across their Country over millennia. First Nations peoples' culture, heritage, knowledge and values are intrinsically connected to Country, and are a central consideration for the management of parks and forests and all aspects of fire management.

Queensland has more than 2 million hectares under formal joint management between the State and the respective First Nations people. Under these arrangements, First Nations people are freehold landowners under the *Queensland Aboriginal Land Act 1991*. The State maintains responsibility for protected area outcomes consistent with the *Nature Conservation Act 1992*.

The *Gurra Gurra Framework* provides the Department's basis for co-designing the management of parks and forests, including culturally responsible and appropriate fire management.

The approach to promoting cultural fire management is broad, ranging from consultation, increasing access to Country and sharing knowledge, interests and values to the implementation of planned burns by First Nations partners.

Shared knowledge and experience of First Nations peoples has informed the bioregional guidelines.

Local partnerships are critical to developing and implementing fire strategies, including identifying and protecting sensitive cultural sites. Healthy Country Plans identify the direction and priorities of First Nations people to keep their Country and culture healthy. These plans are invaluable for informing fire strategies and their implementation in parks and forests in that Country.

Fire management with First Nations people occurs across Queensland's parks and forests. In most situations, the on-ground practice produces low-intensity fire that results in burnt and unburnt patches and does not affect the tree canopy. This approach to fire management is consistent with the intent of this Introductory Volume and the bioregional guidelines.

Plate 1.3 Cultural burn in Dipperu National Park undertaken in conjunction with Barada Barna people, Victor Steffensen and QPWS rangers. *Photo: Lennan Whiting © Qld Govt.*

Additional information

Gurra Gurra Framework (internal)

Planning with First Nations People (internal)

QPWS&P Fire Management Strategy (internal)

Feary 2020, 'Indigenous Australians and fire in south-eastern Australia', in Leavesley et al. *Prescribed burning in Australasia: the science, practice and politics of burning the bush*.

Whitehead et al. 2003, 'Customary use of fire by indigenous peoples in northern Australia: its contemporary role in savanna management', *International Journal of Wildland Fire*, vol. 12, 415–425.

1.3.3 Neighbours

Fire management does not stop at the park or forest boundary. Active engagement with neighbours is often critical to deliver conservation outcomes and reduce bushfire risk on both sides of the fence. It is a shared responsibility.

Understanding the fire history and the type, age-class and condition of vegetation across landscapes outside a park or forest is invaluable in planning and implementing effective fire management on QPWS-managed estate.

Collaborating with QFES and attending local fire meetings (section 1.3.1) is integral to effective neighbour engagement. QPWS staff routinely work with neighbours, successfully delivering planned burns across tenures. The *QPWS Good Neighbour Policy* informs these relationships and activities and aligns with the QBP (section 1.3.1).

Additional information

QPWS Good Neighbour Policy (internal)

Plate 1.4 Montane heath, Mount Maroon, Mount Barney National Park. *Photo: Melinda Laidlaw © Qld Govt.*

2 The fire regime

2.1 Introduction

The fire regime is the sequence of fires at a particular point in the landscape. It consists of:

- fire frequency
- season
- fire intensity
- fire type (sections 2.1.1–2.1.4).

Fire regimes and their associated spatial attributes (extent and patchiness) (section 2.2) influence the structure, composition and function of fire-adapted ecosystems. Whether a fire regime is appropriate (beneficial) or inappropriate (detrimental) depends on the requirements of an ecosystem and/or species (section 3.1) and interacting environmental factors (section 3.2).

The outcomes of a single burn are important, but the outcomes of the fire regime over time and space are more important.

Planned burning to create a mosaic of fire regimes across the landscape over time (section 3.3, Box 3.1 and Appendix 3) reduces the areas of single-aged vegetation and provides greater opportunity to suppress bushfires.

Additional information

DAWE 2022 Fire regimes that cause declines in biodiversity as a key threatening process. (external)

Gill et al. 2002, 'Fire regimes and biodiversity: legacy and vision', in Bradstock et al. eds. *Flammable Australia: the Fire Regimes and Biodiversity of a Continent.*

Plate 2.1 Queensland blue gum *Eucalyptus tereticornis* and Clarkson's bloodwood *Corymbia clarksoniana* open forest, black speargrass *Heteropogon contortus* grassland and Araucarian microphyll vine forest. The fire regimes applied to fire-adapted ecosystems can help protect fire-sensitive values from bushfire, St Bees Island, South Cumberland Islands National Park. *Photo: © Alistair Melzer.*

2.1.1 Fire frequency

Fire frequency describes how often fires occur at a point in the landscape. The time between successive fires is called the fire interval or the between-fire interval.

Fire frequency significantly influences:

- the structure and composition of vegetation communities (e.g. complexity of the litter layer, accumulation of coarse woody debris, abundance and diversity of native legumes and grasses, density and composition of the shrub layer, recruitment and establishment of canopy species)
- fauna habitat
- potential fire intensity.

The recommended fire frequency for an ecosystem is typically based on the requirements of the vegetation communities and their plant species. For example, in communities characterised by obligate seed regenerators, the number of years between seed germination and the first seed set helps guide the minimum fire frequency (section 3.1.1). In contrast, declining health and loss of reproductive vigour in dominant/characteristic grass species often guide the maximum fire frequency for grassy ecosystems.

Fire intervals should be guided by how long an ecosystem takes to regenerate after fire. For example, ecosystems on poor soils in areas of low rainfall (e.g. spinifex grasslands in southwest Queensland) need far longer fire intervals than those on rich soils in areas of high rainfall (e.g. grassy eucalypt woodlands in tropical Queensland).

The guidelines for fire frequency in the bioregional guidelines and the Regional Ecosystem Description Database (e.g. 3–6, 5-12, 8–15 years) provide flexibility. They should not be treated as a formula because many factors can influence an ecosystem such as drought, cyclone or storm damage or above-average rainfall. Undertake regular on-ground inspections, using indicators provided in the bioregional guidelines. Use those observations and knowledge of prevailing climatic conditions and seasonal forecasts, to adjust intervals, if necessary, to achieve objectives in the fire strategy.

Aim to achieve variation in fire frequency, within the acceptable limits, in any single patch of vegetation and across its distribution in land management zones and bushfire mitigation zones (section 1.2.3). The goal is to create a spatial and temporal mosaic of overlapping patches across ecosystems and landscapes that become more diverse and intricate over time (sections 3.3, 5.4.1, 5.4.3 and Appendix 3 for further discussion).

Fire frequency is not the same as the frequency of ignitions in a landscape. The latter may need to be relatively high in some landscapes to ensure that the former is not.

Additional information

Queensland's bioregions (external)
Bioregional Planned Burn Guidelines (external)
Regional Ecosystem Description Database (external)

2.1.2 Season

The time of year of burning has a direct and indirect influence on ecological outcomes, often through its relationship to fire intensity.

Season can have a beneficial or detrimental influence on plant regeneration depending on when burning occurs in relation to flowering, seed availability and active plant growth. For example, cockatoo grass *Alloteropsis semialata* sets seed early in the wet season and does not have a persistent seed bank, so broadscale storm-burning may not be appropriate (case study 3.4). Season influences regeneration of some species through its relationship to fire intensity. For example, germination of hard-seeded species (e.g. legumes) depends on exposure to temperatures sufficient to break dormancy.

Detrimental impacts on regeneration can be minimised or short-lived if:
- seasonal conditions promote a patchy burn
- burning is not regularly undertaken in the same season.

For example, an occasional planned burn during the growing, flowering or fruiting seasons of terrestrial orchids will likely only have short-term detrimental impacts. However, regular burning in those seasons may result in significant population decline or local extinction.

Burns in the wet season (e.g. storm-burning) and early dry season, when the soil and fuel are moist and humidity is high, are typically low-intensity, patchy and more likely to self-extinguish. Planned burns in these conditions typically encourage growth of herbs, including perennial grasses, providing a flush of resources for wildlife. However, they may limit germination in legumes requiring higher temperatures to trigger germination.

Burns during a typical dry season, when there is low soil moisture and cured fuels, increase the risk of extensive and severe fires that lack patchiness (case studies 3.1, 3.4 and 5.1). Even under relatively cool conditions, these fires can:
- destroy critical habitat features, such as logs and hollow-bearing trees
- impact mammals and birds rearing young
- increase weeds due to the slow regeneration of native species.

Planned burns in the dry season also risk reignition (within days to months) and becoming bushfires.

While late wet to early dry season burns, when there is good soil, litter and fuel moisture, are generally favoured, variability remains important. The health and composition of some vegetation communities may be impacted if they are only burned in this 'optimal' seasonal period. Safe burning in the late dry season may be achieved if fuel-reduced areas are established earlier during optimal conditions (section 5.4.2).

A prescriptive approach to burn season is unwise and potentially detrimental.

All seasons are not created equal.

Some wet seasons are relatively dry or start late, while some dry seasons can be wet.

Be prepared to burn when good conditions arise and to postpone burns when conditions are not conducive to achieving the objectives.

Additional information

Bateman & Johnson 2011, ‘The influences of climate, habitat and fire on the distribution of cockatoo grass (*Alloteropsis semialata*) (Poaceae) in the Wet Tropics of northern Australia’, *Australian Journal of Botany*, vol. 59, 315–323.

Miller et al. 2019, ‘Mechanisms of fire seasonality effects on plant populations’, *Trends in Ecology and Evolution*, vol. 34, 1104–1117.

Williams et al. 2004, ‘Soil temperature and depth of legume germination during early and late dry season fires in a tropical eucalypt savanna of north-eastern Australia’, *Austral Ecology*, vol. 29, 258–263.

2.1.3 Fire intensity

Fire intensity is the energy output of a fire. It is influenced by a range of variables, including:

- the amount, arrangement and curing of fuel
- prevailing weather
- slope.

Fire intensity is measured in kilowatts of energy released per metre (kW m-1). Some vegetation communities will naturally burn with higher intensity than others. This is due to their structure and composition (e.g. heaths have a dominance of dense shrubs with highly volatile foliage).

Fire intensity should not be confused with fire severity. Fire severity is an observable effect on the vegetation, such as the degree of scorching or consumption of the litter layer, mid-strata and canopy. For example, a moderate-intensity fire in a tall eucalypt forest will likely only scorch the mid-stratum with no observable effects on the forest canopy. This fire results in moderate fire severity. Whereas a moderate-intensity fire in low shrubland will likely scorch or consume all the canopy, resulting in very high to extreme fire severity. Fire severity classes are provided in *QPWS Planned Burn Guidelines: how to assess if your burn is ready to go*. These classes incorporate fire intensity, average flame height and the physical effect of the fire on vegetation and soil.

High-intensity fires occur when there is low humidity and strong winds (often accompanied by high temperatures) and high, cured fuel loads. They are typically fast-moving and result in high scorch and consumption heights and a more thoroughly combusted ground layer. They have greater direct and indirect impacts on wildlife than lower intensity fires. In some ecosystems they can result in dense regrowth of some species (e.g. wattles *Acacia* spp.).

Fire intensity, and potentially, severity, are increased by:

- using line ignition rather than spot ignition
- burning upslope rather than downslope (section 5.4.3).

Low-intensity fires (Plate 2.3) travel slowly and typically create patchiness, cause little or no crown scorch and remove less ground litter. They therefore limit potential negative impacts of fire, such as loss of fauna habitat and post-fire soil erosion.

However, within an ecosystem, variation in fire intensity, within acceptable limits, plays an important role in maintaining flora and fauna diversity. For example, repeated low-intensity fires may impede the regeneration of legumes with hard seed coats and may not provide the necessary conditions (e.g. bare ground, light) for germination and establishment of eucalypts. Periodic moderate to high-intensity fire may be beneficial in helping prevent the encroachment of *Melaleuca* species into grasslands and heathlands or rainforest species into eucalypt open forests.

The residence time of the fire front also influences outcomes. A slow-moving, lower intensity backing-fire holds heat against stems for longer than a fast-moving, higher intensity fire, and can cause significant damage to some native trees and shrubs. However, prolonging residence time can be useful in managing pest plants, such as rubbervine *Cryptostegia grandiflora*, and reducing woody thickening.

The aim of a planned burn is to provide the fire intensity and residence time that results in the severity and patchiness needed to meet the ecological goals.

Additional information

DERM 2012, *QPWS Planned Burn Guidelines: how to assess if your burn is ready to go* (internal)

Plate 2.2 Bluegrass downs, Albinia National Park. *Photo: Andrew McDougall © Qld Govt.*

Plate 2.3 Low-intensity, patchy planned burn in bluegrass downs with emergent mountain coolabah *Eucalyptus orgadophila,* Albinia National Park. *Photo: Paul Harris © Qld Govt.*

2.1.4 Fire type

There are two broad fire types: below-ground and above-ground fires.

Below-ground fires tend to smoulder rather than flame. Sometimes they are only detectable by an occasional wisp of smoke emerging from the organic soil layer. Below-ground fires may continue long after the above-ground fire has gone out. They can cause extreme damage to ecosystems through their impact on soil structure, chemistry and composition. They destroy microorganisms, soil seed banks, root systems and other underground organs from which plants may regenerate (e.g. tubers, rhizomes) (Plate 2.4).

Below-ground fires in peat swamps (peat fires or deep-seated fires) are particularly destructive given the long timeframe and climatic and environmental conditions required for peat to develop. They can cause significantly altered hydrological regimes and water chemistry resulting in shifts in ecosystem type (e.g. from sedgelands to wooded ecosystems).

Planned burns in peat-based ecosystems, or where there is a deep duff layer, should only be undertaken when the organic layer is wet.

Plate 2.4 a and **b**. A historic peat fire has substantially altered the soil structure and chemistry and the vegetation growing in this swamp. The dead stems (right) are swamp banksia *Banksia robur,* K'gari (Fraser Island), Great Sandy National Park.
Photo: Rhonda Melzer © Qld Govt.

2.2 Fire extent and patchiness

The spatial attributes of fire (extent and patchiness) are influenced by a range of factors including weather conditions, ignition patterns and topography. They are also influenced by the fire regime and fire history (section 2.3).

Fire extent is the area encompassed by a fire event including unburnt patches.

Patchiness refers to both the number, size and distribution of burnt and unburnt patches and the variation in intensity within burnt patches.

The extent of a fire, together with patchiness, significantly influences the survival (during and after fire), recolonisation and recovery of species (sections 3.1.1 and 3.1.2). This influence may be direct (e.g. availability of wildlife refugia, distance to food resources) and indirect (e.g. predator-prey interactions (section 3.2.1), post-fire herbivory (section 3.2.2).

Retaining unburnt patches within the burn extent (Plate 2.5) is particularly important for species with limited dispersal ability and in fragmented landscapes where recolonisation from outside the burn area may be limited or non-existent.

The size and distribution of unburnt patches that best facilitates the survival and recovery of individual species, particularly threatened species, is an active area of research.

Plate 2.5. Planned burn (via helicopter ignition) in hummock grasslands on dunes to reduce the risk of extensive bushfires, Munga-thirri National Park.
Photo: Chris Mitchell © Qld Govt.

2.3 Fire history

Fire history is how the fire regime has occurred over space and time. It is critical to learning from past, and informing future, fire management. Over time, spatial data (e.g. fire history maps and associated information) can be used to assess trends and progress towards longer-term objectives.

Fire history helps with understanding which ecosystems and parts of the landscape are more or less fire-prone. This understanding, coupled with knowing when parts of a landscape have been burnt and how they connect across the landscape, is invaluable in planning and implementing burns.

Fire history is fundamental to the QPWS BRMF and QFES risk reduction programs (sections 1.2.2 and 1.3.1).

Gathering quality fire history is an investment in the present and future (section 5.5.1). The structure and composition of an ecosystem may be the consequence of the fire regime over decades or even centuries. An ecosystem may be significantly altered by a single fire, sometimes many years in the past. Very rarely do fire practitioners have access to fire history data that allows them to explore the potential influence of fire over moderate timeframes, let alone over the long timeframes relevant to many populations or ecosystems. It is our goal to ensure future fire practitioners and fire ecologists have quality fire history information.

Understanding the past is key to understanding the present and the future. It facilitates proactive rather than reactive fire management.

Plate 2.6 Tall wet open eucalypt forest with a rainforest understorey – an ecosystem with long fire intervals. Kroombit Tops National Park, 1992. *Photo: Rhonda Melzer © Qld Govt.*

3 The role of fire in species and ecosystem conservation

Biodiversity conservation is the primary goal of ecological fire management. However, there is limited knowledge of how plant and animal species respond to fire regimes, especially over the long-term and at community and landscape scales. Because of this, fire management goals and approaches are typically based on broad principles and indicators understood to promote biodiversity conservation at the ecosystem level (section 3.3). This is necessary and reasonable, but it is important to continually improve the knowledge on which our ecological fire management is based.

For species, the aim is to build an understanding of those that occur on a park or forest, especially ones with specialist habitat or fire regime requirements. Examine their traits and how these shape the species' responses to fire and fire regimes (section 3.1). Consider factors, including interactions between fire regimes and other disturbances, that influence those responses and hence burn outcomes (section 3.2). As knowledge of fire ecology builds it will inform and refine the guiding principles for effective ecological burning (section 3.3).

Gaps in knowledge about species' fire management requirements are not a reason to avoid burning. Rather, they are a reason to be thoughtful and thorough when developing fire strategies and burn plans and defining ecological objectives. Undertake planned burns based on existing information, record the outcomes, and learn from them. Recording and sharing knowledge and observations are critical parts of fire management and can help bridge knowledge gaps.

The role of organisms, such as invertebrates and fungi, in ecosystem diversity and function, and of fire in their ecology, should not be underestimated (case study 3.5). However, exploration of these topics was beyond the scope of this Introductory Volume. Some references are provided below as an introduction.

Plate 3.1 Some fungi are fire specialists, fruiting (i.e. producing sporocarps) only after fire. *Laccocephalum* sp. fruits within two to three days post-fire.
Photo: © Rhonda Melzer.

Additional information

McMullan-Fisher et al. 2011, ‘Fungi and fire in Australian ecosystems: a review of current knowledge, management implications and future directions’, *Australian Journal of Botany*, vol. 59, 70–90.

Radford & Andersen 2012, ‘Effects of fire on grass-layer savanna macroinvertebrates as key food resources for insectivorous vertebrates in northern Australia’, *Austral Ecology*, vol. 37, 460–469.

Saunders et al. 2021 ‘Limited understanding of bushfire impacts on Australian invertebrates’, *Insect Conservation and Diversity*, vol. 14, 285–293.

Virkki 2014, *Faunal and floral community responses to contemporary fire regimes in eucalypt forests of southeast Queensland*.

Whelan et al. 2002, ‘Critical life cycles of plants and animals: developing a process-based understanding of population changes in fire-prone landscapes’, in Bradstock et al. eds., *Flammable Australia*.

York & Lewis 2018, ‘Understanding the effects of fire on invertebrates in Australian temperate and sub-tropical forests: the value of long-term experiments’, *Australian Zoologist*, vol. 39, 633–645.

3.1 Fire ecology of flora and fauna species

3.1.1 Flora traits

Most Queensland ecosystems are fire-adapted and, at times, fire-promoting, containing plant species with adaptations or traits to survive fire and/or regenerate. Many require fire at times in their life cycle to persist and thrive. Survival and regeneration may be via reproductive or vegetative traits. A species’ response to fire may vary due to factors such as season of burning, age of the plant, microhabitat and site differences and characteristics of the fire.

A small number of plant species that grow in fire-adapted communities have no adaptations to survive fire or regenerate. Their re-establishment relies on the dispersal of seed or other propagules, such as spores, from nearby unburnt sites. The persistence of these species can be a useful indicator of whether burning is maintaining biodiversity at a landscape scale.

The bioregional guidelines consider the known tolerances of plant species to components of the fire regime.

Additional information

Gill 1975, ‘Fire and the Australian flora: a review’, *Australian Forestry*, vol. 38, 4–25.

Gill et al. 1981, *Fire and the Australian biota*.

Gill & Bradstock 1992, ‘A national register for the fire responses of plant species’, *Cunninghamia*, vol. 2, 653–660.

Miller et al. 2019, ‘Mechanisms of fire seasonality effects on plant populations’, *Trends in Ecology and Evolution*, vol. 34, 1104–1117.

Noble & Slatyer 1980, ‘The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances’, *Vegetation*, vol. 43, 5–21.

Plate 3.2 Rusty jacket *Corymbia leichhardtii* woodland with a shrubby understorey of *Calytrix microcoma* and *Grevillea decora,* White Mountains National Park.
Photo: Rhonda Melzer © Qld Govt.

Reproductive traits

Seed banks

Many species have a seed bank (store of seeds) in the soil or canopy. The persistence and longevity of these seed banks vary between species and with environmental conditions. Fire regimes, and associated burn and post-burn conditions, influence the depletion of the seed bank through seed death (e.g. seeds with high moisture content are less tolerant to heat) and germination, and the replenishment of the seed bank.

Some species have long-lived soil seed banks with specific adaptations to fire. These include hard-seeded species such as legumes (e.g. many peas and wattles *Acacia* spp.) (Plates 3.3 to 3.5). They typically germinate *en masse* after an intense fire. The heat cracks the seed coat allowing moisture to penetrate and germination to occur. Germination rates will be low if their seeds are not exposed to sufficiently elevated temperatures. Soil-stored seeds of some other species require the chemicals in smoke to break their dormancy and so enable them to germinate. Long-lived soil seed banks may not be exhausted by a single fire, so conferring resilience to relatively frequent fire.

Plate 3.3 The native legume, native sarsaparilla *Hardenbergia violacea*, flowering after mass germination where a large log burnt out in a bushfire, Blackdown Tableland National Park. *Photo: Rhonda Melzer © Qld Govt.*

Plate 3.4 *Hardenergia violacea*. *Photo: Rhonda Melzer © Qld Govt.*

In some shrub and tree species, seeds are protected inside woody fruits held in the canopy. These keep some of the seeds in viable condition for many years. The woody fruits open with fire, releasing the seeds (Plates 3.5 and 3.6). Examples include wallum hakea *Hakea actites* and most of Queensland's *Banksia* species; the exception is coastal banksia *Banksia integrifolia*. Canopy seed banks are typically exhausted by a single fire.

Plate 3.5 (above) *Acacia* sp. seedling germinated from the soil seed bank and wallum banksia *Banksia aemula* seedling (front) germinated from seed released from woody fruit in a fire. *Photo: Rhonda Melzer © Qld Govt.*

Plate 3.6 (right) Swamp banksia *Banksia robur* fruits opened with fire. *Photo: Rhonda Melzer © Qld Govt.*

The term obligate seed regenerator or obligate seeder is used to describe species where the plant is killed by fire and regeneration is solely from soil- or canopy-stored seeds. They are common in 'heathy' communities. Examples of obligate seeders include blue banksia *Banksia plagiocarpa* (vulnerable), tiny wattle *Acacia baueri* subsp. *baueri* (vulnerable), Brisbane golden wattle *Ac. fimbriata*, purple-flowered wattle *Ac. purpureopetala* (vulnerable), parrot pea *Dillwynia retorta*, pointed-leaf hovea *Hovea acutifolia*, *Pultenaea petiolaris*, large-leaved hop bush *Dodonaea triquetra*, *D. vestita*, *Allocasuarina littoralis* and coastal cypress pine *Callitris columellaris*.

The persistence of obligate seeders in an ecosystem or landscape is a useful indicator of effective ecological fire management. For these plants to persist, the fire interval must be longer than the time between seed germination and the first seed crop (the primary juvenile period). Ideally, the fire interval is long enough to allow several seed crops to be produced between fires.

Mosaic burning (section 3.3, Box 3.1 and Appendix 3) helps provide security in time and space for obligate seeders, particularly in highly fire-prone areas where it may be necessary to implement planned burns at intervals shorter than ideal for these species.

Some of Queensland's obligate seeder shrubs have a relatively short primary juvenile period (time taken by plants to flower after germination from seed, e.g. two to four years). Obligate seeder trees have a relatively long primary juvenile period (e.g. approximately 20 years for lancewood *Acacia shirleyi*).

The short-lived seeds of species that do not have seed banks may be protected from fire if they are insulated beneath soil or held high in the canopy at the time of the fire (e.g. eucalypt seed in woody capsules). In these species, there is often significant seed fall post-fire, and the seed stock can be exhausted by a single fire.

The environmental conditions immediately after a fire (e.g. reduced competition, increased light on the soil surface, increased nutrients) are ideal for seed germination and seedling establishment if there is adequate soil moisture. Seedling establishment can vary depending on the season of fire. For example, fires in the early wet season provide a longer period for growth and plant establishment than fires at the onset of the dry season.

Fire-stimulated reproduction

This is when flowering and/or fruiting increases and synchronises after fire. Factors contributing to this phenomenon likely include:

- heat
- smoke
- foliage loss
- reduced competition
- increased availability of light
- increased nutrients.

Fire-stimulated reproduction can provide benefits, including enhanced pollination, satiated seed predators and so increased germination rates, and the ability to take advantage of the post-fire conditions. Such species include cockatoo grass *Alloteropsis semialata*, Christmas bells *Blandfordia grandiflora*, cycads *Cycas* spp., forked sundew *Drosera binata*, zamia palms *Macrozamia* spp., greenhood orchids *Pterostylis* spp. and grass trees *Xanthorrhoea* spp. (Plates 3.7–3.11). Most species with this trait can flower and/or fruit without fire but some only do so after fire.

The season of burning may affect species with fire-stimulated reproduction. For example, if fire occurs just before or during the peak flowering season, it may delay or fail to stimulate flowering. This will impact seed production.

Plate 3.7 Forked sundew *Drosera binata* resprouted from rootstock in peat swamp after fire.
Photo: Rhonda Melzer © Qld Govt.

Plate 3.8 *Drosera binata* flowering within weeks of fire.
Photo: © W J McDonald.

Plate 3.9 *Macrozamia moorei*, Buckland Tableland National Park.
Photo: Rhonda Melzer © Qld Govt.

Plate 3.10 *Macrozamia miquelii* 'coning' within two months post-fire.
Photo: © Rhonda Melzer.

Plate 3.11 *Cycas ophiolitica* with pre- and post-fire fruits.
Photo: Rhonda Melzer © Qld Govt.

Vegetative traits

Resprouters are generally able to rapidly regenerate after fire. However, the regeneration rate may be influenced by interactions between the fire regime, post-fire conditions and the plants' seasonal cycle. For example, if fire occurs when a resprouters' reserves are low (e.g. at the beginning of the growing season), it may be less likely to survive or rapidly and vigorously resprout.

The timing of fire during the growing season may also affect survival and vigour in the years after fire. For example, plants burnt late in the growing season will have little time to regrow and replenish reserves before the dry season.

Epicormic regrowth

This is a common and conspicuous adaptation in eucalypts but also occurs in a range of other species, such as forest oak *Allocasuarina torulosa* and wallum banksia *Banksia aemula* (Plates 3.12 and 3.13). Epicormic buds occur on the trunk and branches and are protected by the bark. They remain dormant until fire or some other disturbance (e.g. storm or severe insect infestation) damages the crown. Epicormic resprouting enables plants to rapidly re-establish photosynthetic function after fire.

Plate 3.12 Epicormic regrowth on a wallum banksia *Banksia aemula* after a severe bushfire.
Photo: Rhonda Melzer © Qld Govt.

Plate 3.13 Epicormic regrowth on *Eucalyptus* sp. after a severe bushfire.
Photo: Robert Ashdown © Qld Govt.

Unharmed apical buds

Some species, including cabbage palms *Livistona* spp., grass trees *Xanthorrhoea* spp., cycads such as *Macrozamia miquelii* (Plate 3.10) and the Marlborough blue *Cycas ophiolitica* (endangered) (Plate 3.14) and tree ferns such as soft tree fern *Dicksonia antarctica* (Plate 3.15) regenerate after fire from unharmed apical (terminal) buds.

These buds are surrounded by moist leaf bases, and while the conflagration of the leaves can be a spectacle, it is usually rapid, leaving the buds unharmed.

Plate 3.14 Marlborough blue *Cycas ophiolitica* with new foliage from apical buds within days of fire, Mount Archer State Forest. *Photo: Rhonda Melzer © Qld Govt.*

Plate 3.15 Soft tree fern *Dicksonia antarctica* resprouting after bushfire from apical buds, Main Range National Park. *Photo: Harry Hines © Qld Govt.*

Basal stem buds

Many species resprout from buds at the base of the stem that are protected from the heat of the fire by plant tissue and soil. The shoots grow quickly and facilitate rapid regeneration. Many rainforest species resprout from basal stem buds, especially those growing along the ecotone with fire-adapted eucalypt communities.

Lignotubers

A lignotuber is a woody bud and food storage organ that develops when plants are seedlings. The bud and food reserves help seedlings rapidly take advantage of additional space and light available after fire.

They are a common adaptation in eucalypts but also occur in other species, including wallum banksia *Banksia aemula*, swamp banksia *Banksia robur* and wallum hakea *Hakea actites*.

Lignotubers persist throughout the life of some species. They are insulated by soil at least initially but can become large, visible structures such as in some mallee eucalypts (Plates 3.16 a and b). In many other species, they disappear as the stem enlarges.

Lignotuberous ‘seedlings’ can persist in the ground layer for many years with stem shoots being killed multiple times by fire or other disturbances.

While most Queensland eucalypts have lignotubers, there are exceptions. Flooded gum *Eucalyptus grandis* and blackbutt *E. pilularis* do not have lignotubers, making their seedlings more susceptible to fire.

Plate 3.16 Lignotuber on brushbox *Lophostemon confertus*. **a.** unburnt **b.** resprouting after a planned burn. *Photos: © Rhonda Melzer.*

Other subterranean organs

Root suckers, underground stems, rhizomes (underground horizontal stems) and fleshy underground storage organs (bulbs, corms, tubers) are usually protected from fire beneath the soil. This enables plants to rapidly regenerate after fire (Plates 3.17 and 3.18).

Root suckering is prevalent in wattles *Acacia* spp. It is also common among rainforest species, including celerywood *Polyscias elegans*, red kamala *Mallotus philippensis* and cheese tree *Glochidion ferdinandi*.

Examples of species with underground stems include cycads, such as Byfield fern *Bowenia serrulata*, *Macrozamia platyrhachis* (endangered) and *M. lomandroides* (endangered).

Plate 3.17 *Blechnum neohollandicum* resprouting from the rhizome post-fire, Main Range National Park. *Photo: Robert Ashdown © Qld Govt.*

Rhizomes are common in grasses, sedges, rushes, ferns and lilies, such as blue flax-lilies *Dianella* spp. and rush lilies *Tricoryne* spp.

Species that resprout from bulbs include field lily *Crinum angustifolium* and Moreton Bay lily *Proiphys cunninghamii*. Golden weathergrass *Hypoxis pratensis* resprouts from corms. Tubers are common in ground orchids, sedges and lilies.

Plate 3.18 Gristle fern *Blechnum cartilagineum* resprouting from rhizomes post-fire:
a. two months post-fire
b. six months post-fire, Kroombit Tops National Park.
Photos: Harry Hines © Qld Govt.

Additional information

Regenerative strategies:

Bateman & Johnson 2011, 'The influences of climate, habitat, and fire on the distribution of cockatoo grass (*Alloteropsis semialata*) (Poaceae) in the Wet Tropics of northern Australia', *Australian Journal of Botany*, vol. 59, 315–323.

Baker et al. 2022, 'Rainforest persistence and recruitment after Australia's 2019–2020 fires in subtropical, temperate, dry and littoral rainforests', *Australian Journal of Botany*, vol. 70, 189–203.

Bradstock et al. eds. 2002, *Flammable Australia. The fire regimes and biodiversity of a continent.*

Conroy 2012, *The effects of fire and fragmentation upon two threatened coastal heath species, Acacia baueri* ssp. *baueri* (Mimosaceae) *and Blandfordia grandiflora* (Blandfordiaceae).

Williams et al. 2004, 'Soil temperature and depth of legume germination during early and late dry season fires in a tropical eucalypt savanna of north-eastern Australia', *Austral Ecology*, vol. 29, 258–263.

Williams et al. 2017, 'The fire ecology of *Allocasuarina littoralis* and *Banksia plagiocarpa* in montane heath of the southern Wet Tropics', *North Queensland Naturalist*, vol. 47, 43–48.

Fire-stimulated flowering:

Griffith & Rutherford 2020, 'Flowering of *Blandfordia grandiflora* (Christmas bells) in response to fire frequency and temperature', *Australian Journal of Botany*, vol. 68, 449–457.

Lamont & Downes 2011, 'Fire-stimulated flowering among resprouters and geophytes in Australia and South Africa', *Plant Ecology*, vol. 212, 2111–2125.

Pyke 2017, 'Fire-stimulated flowering: a review and look to the future', *Critical Review Plant Science*, vol. 36, 179–189.

3.1.2 Fauna traits

Four key processes affecting how animal species respond to fire are summarised below together with factors that influence them.

1. **Impact of fire on the mortality of individuals** is influenced by:

- characteristics of the fire (e.g. rate of spread, intensity, season)
- the life stage of the species (e.g. eggs or young in an exposed nest)
- traits of the species (e.g. mobility; use of shelter sites like leaf litter, rock crevices and tree hollows; physiological tolerances; site fidelity)
- characteristics of the habitat (e.g. availability of suitable, insulative shelter and natural refugia; proximity to unburnt areas).

2. **Post-fire survival inside the burned area** depends on:

- availability of critical resources (e.g. food, cover, shelter and nesting sites)
- degree of specialisation (e.g. broad versus narrow dietary requirements)
- dependence on specific habitat (e.g. litter layer, coarse woody debris, tree hollows)
- susceptibility to predation and/or competition.

Reduced food and shelter after fire, along with increased susceptibility to predation, is a common cause of decline in some threatened faunal groups, including mammals.

3. **Recolonisation of the burned area** (from within or outside) depends on:

- spatial attributes of the fire and landscape (e.g. proximity to unburnt refugia, connectivity or barriers)
- availability of critical resources (e.g. food, cover, shelter)
- traits of the species (e.g. ability to disperse, mobility).

4. **Reproduction and population recovery** are influenced by:

- reproductive strategies and patterns (e.g. opportunistic versus highly seasonal breeding, length of gestation, weaning and juvenile periods, clutch or litter size)
- the recovery rate of breeding sites (e.g. availability of nest sites, flooding of wetlands for aquatic breeding species)
- the number of breeding opportunities between fires
- prevailing weather conditions (e.g. typical versus extreme weather, such as floods, cyclones, heat waves, drought).

These variables mean animal species occurring in fire-adapted ecosystems have different responses to individual fires and fire regimes. This can be a daunting prospect for land managers and fire practitioners. However, most species in fire-adapted ecosystems do not require targeted fire management intervention provided the principles for ecological burning outlined in section 3.3 are applied.

The subset of fauna species and their habitat that need targeted fire management are those that have:

- small and/or disjunct populations
- specific habitat requirements that are rare in the landscape or critical at certain times (e.g. nesting habitat, key food resources)
- face threats that are increased by fire (e.g. predation by feral cats *Felis catus*).

Consideration of the four key processes and the factors influencing them helps to identify known or likely vulnerabilities of species to fire regimes. This information assists with fire management planning and implementation. Some examples are provided in case studies 3.1–3.5.


a


b

Plate 3.19 Approximately 300 Australian native vertebrate species rely on hollow-bearing trees for part of their life cycle. At least 95 of these species occur in Queensland:

a. heath shadeskink *Saproscincus oriarus* peering out from a partially burnt apical hollow of a sword sedge *Gahnia sieberiana* stem. Some vertebrates use very small hollows. In this case, hollow *Gahnia* stems sheltered animals when little other cover remained after a high-severity fire in sedgeland (Hines et al. 2015). *Photo: © Ed Meyer.*

b. sulphur-crested cockatoo *Cacatua galerita* nesting hollow in Queensland blue gum *Eucalyptus tereticornis*. *Photo: © Andrew McDougall.*

Additional information

Andersen 2021, 'Faunal responses to fire in Australian tropical savannas: insights from field experiments and their lessons for conservation management', *Diversity and Distributions*, vol. 27, 828–843.

Clarke 2008, 'Catering for the needs of fauna in fire management: science or wishful thinking', *Wildlife Research*, vol. 35, 385–394.

DEHP 2017b, *Field guide for managing fire in northern bettong habitat.*

Dixon et al. 2018, 'The disproportionate importance of long-unburned forests and woodlands for reptiles', *Ecology and Evolution*, vol. 8, 10952–10963.

Flanagan-Moodie et al. 2018, 'Prescribed burning reduces the abundance of den sites for a hollow-using mammal in a dry forest ecosystem', *Forest Ecology and Management*, vol. 429, 233–243.

Hines et al. 2015, 'First Queensland records of the heath shadeskink (*Saproscincus oriarus*)', *The Queensland Naturalist*, vol. 53, 37–45.

Radford et al. 2020, 'Prescribed burning benefits threatened mammals in northern Australia', *Biodiversity and Conservation*, vol. 29, 2985–3007.

Santos et al. 2022, 'Beyond inappropriate fire regimes: a synthesis of fire-driven declines of threatened mammals in Australia', *Conservation Letters*, e12905.

Shaw et al. 2021 'Unburnt habitat patches are critical for survival and in situ population recovery in a small mammal after fire', *Journal of Applied Ecology*, vol. 58, 1325–1335.

Stone et al. 2022, 'Reduced fire frequency over three decades hastens loss of the grassy forest habitat of an endangered songbird', *Biological Conservation*, vol. 270, 109570.

Tuft et al. 2012, 'Fire and grazing influence food resources of an endangered rock-wallaby', *Wildlife Research*, vol. 39, 436–445.

Verdon & Clarke 2022, 'Can fire-age mosaics really deal with conflicting needs of species? A study using population hotspots of multiple threatened birds', *Journal of Applied Ecology*, vol. 59, issue 8, 1–14.

von Takach et al. 2022, 'Long unburnt habitat is critical for the conservation of threatened vertebrates across Australia', *Landscape Ecology*, vol. 37, 1469–1482.

Whelan et al. 2002, 'Critical life cycles of plants and animals: developing a process-based understanding of population changes in fire-prone landscapes', in Bradstock et al. eds., *Flammable Australia: the Fire Regimes and Biodiversity of a Continent*.

Williams et al. 2020, 'Black-throated finch habitat values promoted by patchy fire', *North Queensland Naturalist*, vol. 50, 38–43.

Woinarski & Recher 1997, 'Impact and response: a review of the effects of fire on the Australian avifauna', *Pacific Conservation Biology*, vol. 3, 183–205.

Case study 3.1: Carpentarian grasswren

Carpentarian grasswren *Amytornis dorotheae* is an endangered species endemic to the southern Gulf of Carpentaria region in northern Australia. The species has declined, and populations are now fragmented due to extensive bushfires. Carpentarian grasswrens are dependent on mature spinifex *Triodia* spp. hummock grassland. These communities are highly fire-prone and burn extensively without active fire management (see case study 5.1).

Plate 3.20
Carpentarian grasswren *Amytornis dorotheae*.
Photo: © Mark Sanders (EcoSmart Ecology).

Carpentarian grasswrens can use habitat within three to four years post-fire. However, they probably require long-term fire refugia in the landscape for population persistence. Refuge areas likely provide the only reliable source for dispersal and recolonisation of burnt landscapes.

Recolonisation of extensive areas that have experienced repeated homogenous fires is likely to be very slow because of the birds' poor dispersal ability.

Active fire management is required to maintain unburnt refugia. This includes identifying likely habitat and applying fine-scale fire within it to prevent total combustion. Annual planned fire is also necessary in the broader landscape to provide a mosaic of age-classes and prevent broadscale, late dry season bushfires.

In Queensland, Boodjamulla National Park is the only protected area where Carpentarian grasswrens occur. The proactive late wet/early dry season burn program implemented since 2012 has created a mosaic of age-classes across the landscape, including relatively long unburnt refugia (see case study 5.1). Whilst bushfires still occur, they are now less extensive and add to the diversity of fire regimes occurring at the park. Ongoing monitoring of Carpentarian grasswrens shows the population at Boodjamulla is persisting (BirdLife Australia unpub. data) and has the potential to increase in coming years.

Additional information

Ezzy 2022, 'Breaking the wildfire cycle: progressive fire management can shift fire regimes and improve ecosystem condition. A case study from a large conservation reserve in northern Australia', *Rangelands Journal*.

Harrington & Murphy 2015, 'The distribution and conservation status of Carpentarian grasswrens (*Amytornis dorotheae*), with reference to prevailing fire patterns', *Pacific Conservation Biology*, vol. 21, 291-297.

Melzer et al. 2019, 'Health Checks: a simple tool for assessing the condition of values and effectiveness of reserve management', *PARKS*, vol. 25, 67–78.

Stoetzel et al. 2020, 'Modelling the habitat of the endangered Carpentarian grasswren (*Amytornis dorotheae*): the importance of spatio-temporal habitat availability in a fire-prone landscape', *Global Ecology and Conservation*, vol. 24, 01341.

TSSC 2016, *Conservation advice Amytornis dorotheae Carpentarian grasswren*.

Case study 3.2: ground parrot

The ground parrot *Pezoporus wallicus wallicus* has a patchy distribution in eastern Australia. In Queensland, it is listed as a vulnerable species and is restricted to the Great Sandy region and the Sunshine Coast.

Ground parrots are dependent on highly fire-prone heaths and sedgelands. Patch occupancy and population density is affected by time since fire, fire frequency and proximity to recolonisers.

Ground parrots require dense vegetation, especially for nesting. They are absent from recently burnt heath with peak abundance in southeast Queensland occurring within five to eight years after fire. Very long unburnt heathlands appear less suitable for ground parrots and can be affected by woody thickening by swamp paperbark *Melaleuca quinquenervia*.

The population in Mooloolah River National Park is thought to be extinct due to extensive bushfires and an inability to recolonise due to urban development isolating the park from other occupied habitat.

Understanding the relationship between population density and fire regime has significantly influenced fire management in Noosa and Great Sandy National Parks. Objectives in the fire strategies for these parks include maintaining a mosaic of age-classes in heaths and sedgelands, managing woody thickening and preventing broadscale bushfires.

Plate 3.21 Eastern ground parrot *Pezoporus wallicus wallicus*. *Photo: © Mark Sanders (EcoSmart Ecology).*

Additional information

Baker et al. 2010, 'Managing the ground parrot in its fiery habitat in south-eastern Australia', *Emu-Austral Ornithology*, vol. 110, 279–284.

McFarland 1991a, 'The biology of the ground parrot, *Pezoporus wallicus*, in Queensland. II. Spacing, calling and breeding behaviour', *Wildlife Research*, vol. 18, 185–197.

McFarland 1991b, 'The biology of the ground parrot, *Pezoporus wallicus*, in Queensland. III. Distribution and abundance', *Wildlife Research*, vol. 18, 199–213.

Meredith et al. 1984, 'The ground parrot (*Pezoporus wallicus* Kerr) in south-eastern Australia: a fire adapted species?', *Australian Journal of Ecology*, vol. 9, 367–380.

Case study 3.3: greater gliders

Two species of greater glider occur in Queensland's eucalypt forests: the vulnerable northern greater glider *Petauroides minor* and the endangered central greater glider *P. armillatus*.

Greater gliders depend on hollow-bearing trees for shelter and breeding. The loss of this key resource has been closely linked to population declines. While vegetation clearing and timber harvesting are leading contributors to this threat, loss through planned burns and bushfires is also significant.

Fires that scorch or consume the canopy have at least short to medium-term negative impacts on greater glider occurrence. This is due to loss of food (i.e. eucalypt foliage) and reduced protection from predators (e.g. powerful owl *Ninox strenua*).

Post-fire recolonisation and repopulation by greater gliders can lag significantly behind the regeneration of their fire-adapted habitat. This is due to their low reproductive output (one offspring per year) and poor dispersal ability.

Understanding these threats to greater gliders reinforces the need to follow key principles of planned burning in forests, particularly:

- burning with sufficient soil and fuel moisture and appropriate prevailing weather to avoid canopy scorch and reduce the risk of fire at the base of hollow-bearing trees.
- raking litter away from the base of hollow-bearing trees may be warranted, especially along roads used for ignition and in small parks with a logging history.

Plate 3.22 Central greater glider *Petauroides armillatus*. *Photo: © Josh Bowell (Qld Glider Network).*

Case study 3.3: greater gliders (continued)

Plate 3.23 Planned burn resulting in canopy scorching in central greater glider *Petauroides armillatus* habitat.
Photo: Harry Hines © Qld Govt.

Plate 3.24 Felling of a large, old-growth, hollow-bearing tree in central greater glider *Petauroides armillatus* habitat after it became a safety risk following a planned burn. Raking litter away from the tree base before ignition would have protected this critical habitat feature.
Photo: Harry Hines © Qld Govt.

Additional information

Campbell-Jones et al. 2022, 'Fire severity has lasting effects on the distribution of arboreal mammals in a resprouting forest', *Austral Ecology*.

DCCEEW 2022, *Conservation advice for Petauroides volans (greater glider (southern and central))*.

Eyre et al. 2010, 'Effects of forest management on structural features important for biodiversity in mixed-age hardwood forests in Australia's subtropics', *Forest Ecology and Management*, vol. 259, 534–546.

Eyre et al. 2022, *Guide to greater glider habitat in Queensland*.

McLean et al. 2018, 'The threatened status of the hollow dependent arboreal marsupial, the greater glider (*Petauroides volans*), can be explained by impacts from wildfire and selective logging', *Forest Ecology and Management*, vol. 415, 19–25.

Case study 3.4: golden-shouldered parrot (alwal)

The golden-shouldered parrot *Psephotus chrysopterygius* only occurs in the grasslands and savannas of Cape York Peninsula. This species has suffered significant declines due to complex, interacting threats, including grazing by cattle *Bos* sp., grazing and rooting by feral pigs *Sus scrofa*, increased predation, woody thickening and altered fire regimes (changes to traditional Aboriginal burning practices that promote sustainable habitat and food).

The nesting and feeding habitat of golden-shouldered parrots is impacted by woody thickening of broad-leaved paperbark *Melaleuca viridiflora*. Woody thickening reduces the availability of suitable nest sites (termite mounds), increases predation at nests and reduces grass cover and diversity.

A natural shortage of parrot food occurs annually in the early wet season. This is due to grass seed germination and rapid ground cover growth obscuring fallen seeds. Food shortages can be made worse by a lack of storm-burning (see below), cattle grazing and/or pigs eating the roots of key species.

Late dry season fires typically remove critical seed resources from extensive areas. They also likely increase impacts from predators such as feral cats *Felis catus* that target burnt areas for hunting.

Decades of research on golden-shoulder parrot ecology underpins the management guidelines for the species (Crowley et al. 2004). Two key recommendations for fire management are:

1. storm-burning every two to four years
2. undertaking early dry season burning to protect critical habitat from dry season bushfires.

Storm-burning achieves several critical outcomes for golden-shouldered parrots, including:

- removing ground cover, exposing ungerminated seeds and killing germinating seeds so increasing available food
- increasing the density of seeding herbs so increasing feeding efficiency
- delaying flowering but increasing subsequent seed production of cockatoo grass *Alloteropsis semialata* in burnt areas. A mosaic of storm-burn patches within the landscape can therefore result in the availability of this high-value food resource over a longer period.

Storm-burning needs to occur within the week following the first heavy rains (≥50mm over 72 hours) of the wet season.

In QPWS protected areas where golden-shouldered parrots occur, these recommendations are implemented through a program of annual aerial planned burns and periodic storm-burns.

Additional information

Crowley et al. 2004, *Management guidelines for golden-shouldered parrot conservation*.

Garnett & Crowley 2002, *Recovery plan for the golden-shouldered parrot Psephotus chrysopterygius 2003–2007*.

TSSC 2017, *Conservation advice Psephotus chrysopterygius (golden-shouldered parrot, alwal)*.

Plate 3.25 Golden-shouldered parrot *Psephotus chrysopterygius*.
Photo: © Mark Sanders (EcoSmart Ecology).

Case study 3.5: northern bettong

The endangered northern bettong *Bettongia tropica* suffered massive range contractions in the 1900s. It is now confined to moist to wet upland grassy eucalypt woodlands and tall open forests on the western edge of the Wet Tropics.

Conserving this species depends on active fire management within its core habitat, including across several parks and forests. Predator control, particularly post-fire, may also be important.

Plate 3.26 Northern bettong *Bettongia tropica*.
Photo: Adam Creed © Qld Govt.

The northern bettong's core habitat is where two critical food resources overlap: truffles (hypogeal sporocarps from ectomycorrhizal fungi) growing on the roots of eucalypts and *Allocasuarina* spp. and the fleshy roots of cockatoo grass *Alloteropsis semialata*. These food resources vary spatially and temporally and require appropriate fire regimes. Ground cover, another important requirement for shelter, nesting and avoiding predators, is reduced by extensive fire.

The Department, in collaboration with World Wildlife Fund and James Cook University, developed guidelines (DEHP 2017a) for managing fire in northern bettong habitat. Three principles are recommended:

- burn to avoid extensive, high-intensity fires
- burn to create a mosaic of fire regimes
- maintain unburnt refugia within the home range.

Achieving the desired outcomes is complicated by ecosystem variability, woody thickening, rainforest establishment, altered forest structure from logging and the impact of stock, feral pigs *Sus scrofa* and ecosystem-changing weeds, such as lantana *Lantana camara*.

A field guide (DEHP 2017b) was developed to help with planning, implementing and monitoring burn programs to recover or maintain northern bettong habitat. The field guide draws on the experience of fire practitioners and research outcomes.

Additional information

DEHP 2017a, *Guidelines for managing fire in northern bettong (Bettongia tropica) habitat*.
DEHP 2017b, *Field guide for managing fire in northern bettong habitat*.
TSSC 2016b, *Conservation advice Bettongia tropica northern bettong*.

3.2 Interactions between fire and other disturbances

3.2.1 Fire and predators

Burnt areas can increase opportunities for native or introduced predators because of the reduced shelter for prey and easier access for predators.

Native predators that may target burnt areas include owls, raptors, dingoes *Canis familiaris* (dingo) and quolls *Dasyurus* spp. Introduced predators include cane toads *Rhinella marina*, cats *Felis catus* and red foxes *Vulpes vulpes* (see case studies 3.4 and 3.5).

Maintaining a mosaic of burnt and unburnt patches across the landscape can help reduce the risk of concentrated predation. Burning under conditions that ensure shelter (e.g. logs and tussock grasses) is retained within burnt areas will also help reduce predation.

Where there is a heightened risk of predation on threatened species, predator control may need to be integrated into the burn program. Herbivore control may also be required, where predator control results in increased grazing or browsing by introduced herbivores or overabundant native herbivores (section 3.2.2).

3.2.2 Fire and herbivores

Heavy grazing or browsing (by stock, feral or native herbivores) following fire impacts fauna that rely on the regenerating vegetation for food, nesting or shelter including for protection from predation (see case studies 3.4 and 3.5). Ground-dwelling and ground-nesting fauna are likely to be most impacted.

There can be indirect impacts on food availability. For example, reduced vegetation biomass results in fewer invertebrates which in turn impacts fauna species dependent upon invertebrate food sources.

Burning encourages fresh growth that is typically more palatable and nutritious than unburnt vegetation. The fresh growth is a valuable, albeit short-term, resource for native herbivores including macropods and invertebrates. However, grazing or browsing of new growth may be detrimental if it impedes flowering, fruiting or seedling establishment. Seedlings of Queensland blue gum *Eucalyptus tereticornis*, for example, are highly palatable to native and introduced herbivores and post-fire grazing can significantly reduce recruitment.

Selective grazing or browsing after fire is likely to disproportionately impact highly palatable plant species with a restricted distribution. However, declines can also occur in widespread palatable species if intensive grazing or browsing occurs after each fire. A well-known example is kangaroo grass *Themeda triandra* (Plate 3.27). Kangaroo grass is a perennial tussock grass with low rates of seed viability and a relatively small soil seed bank. Seed production can be stimulated by fire, but recruitment after fire is rarely significant. However, it does resprout readily after fire and responds well to frequent burning (e.g. two to five years), particularly outside the growing season. Populations may decline to local extinction if the fire interval is long (e.g. >10 years). The positive response to burning is likely due to reduced competition with other species. Kangaroo grass has declined across Australia because of stock grazing. Heavy grazing after a fire is likely to be highly detrimental to this species.

Creating a mosaic of burnt and unburnt areas across a wide area, rather than a small number of burnt areas, and timing burns to ensure conditions conducive to rapid regeneration, can help minimise the risk of intensive grazing or browsing. On the other hand, attracting grazers or browsers to recently burnt areas may be an appropriate strategy when the intent is to control those species.

Integrating the control of unauthorised stock, introduced herbivores and/or over-abundant macropods with the burn program may be important to reduce grazing impacts after fire.

Additional information

Fire, predators and herbivores – impacts on fauna:

Hradsky et al. 2017, 'Responses of invasive predators and native prey to a prescribed forest fire', *Journal of Mammalogy*, vol. 98, 835–847.

Hradsky 2020, 'Conserving Australia's threatened native mammals in predator-invaded, fire-prone landscapes', *Wildlife Research*, vol. 47, 1–15.

Leahy et al. 2015, 'Amplified predation after fire suppresses rodent populations in Australia's tropical savannas', *Wildlife Research*, vol. 42, 705–716.

Legge et al. 2019, 'Interactions among threats affect conservation management outcomes: livestock grazing removes the benefits of fire management for small mammals in Australian tropical savannas', *Conservation Science and Practice*, vol. 1, e52.

McGregor et al. 2014, 'Landscape management of fire and grazing regimes alters the fine-scale habitat utilisation by feral cats', *PloS ONE*, vol. 9, e109097.

McGregor et al. 2016, 'Extraterritorial hunting expeditions to intense fire scars by feral cats', *Scientific Reports*, vol. 6, article 22559.

Radford et al. 2021, 'Landscape-scale effects of fire, cats, and feral livestock on threatened savanna mammals: unburnt habitat matters more than pyrodiversity', *Frontiers in Ecology and Evolution*, vol. 9, article 739817.

Tuft et al. 2012, 'Fire and grazing influence food resources of an endangered rock-wallaby', *Wildlife Research*, vol. 39, 436–445.

Ecology and management of kangaroo grass *Themeda triandra*:

Morgan & Lunt 1999, 'Effects of time-since-fire on the tussock dynamics of a dominant grass (*Themeda triandra*) in a temperate Australian grassland', *Biological Conservation*, vol. 88, 379–386.

Snyman et al. 2013, '*Themeda triandra*: a keystone grass species', *African Journal of Range and Forage Science*, vol. 30, 99–125.

Plate 3.27 Cullen's ironbark *Eucalyptus cullenii* woodland with a ground layer dominated by kangaroo grass *Themeda triandra* and black speargrass *Heteropogon contortus,* Einasleigh Uplands.
Photo: Gary Wilson © Qld Govt.

3.2.3 Fire and weeds

Weeds most often invade disturbed areas (including burnt areas), but some gradually invade healthy ecosystems, particularly if there is a ready source of propagules (e.g. seeds, spores) nearby.

Fire is most likely to promote weed invasion if it results in:

- widespread removal of ground cover
- bare ground for extended periods
- altered soil properties
- damaged fire-sensitive communities.

Planned burns for ecological purposes should not result in the above conditions. However, they do result in reduced competition and increased light and nutrients, which may facilitate the invasion and establishment of weeds in some circumstances. Weed invasion post-burn may be promoted where there are other disturbances such as stock grazing or feral pigs *Sus scrofa* rooting.

The risk of promoting weeds by planned burning can be minimised by careful planning, preparation, implementation and follow-up. For example, knowing what weeds pose a risk to the proposed burn area, where they occur and how they disperse and germinate can inform logistics, such as access routes to the burn area, timing and lighting tactics and whether pre-burn and/or post-burn weed control is required. Management of stock grazing and timing of feral animal control programs around burns should also be considered.

Burning with good soil moisture encourages rapid regeneration of native plants, which minimises the opportunity for weeds to establish.

Vehicles and equipment used for planned burns and bushfire response must be free of weed propagules and plant pathogens.

Many weeds that emerge after fire do not affect ecosystem structure and composition or long-term ecological function. However, there are some weeds with potential to significantly alter composition, structure and ecosystem function and/or affect the ability to manage fire. These are referred to as ecosystem-changing weeds. They include:

- high-biomass grasses (e.g. gamba grass *Andropogon gayanus*, buffel grass *Cenchrus ciliaris*, thatch grass *Hyparrhenia rufa* and grader grass *Themeda quadrivalvis*) and
- shrubs (e.g. lantana *Lantana camara*) that can substantially increase the intensity of fires
- low-biomass grasses (e.g. Indian couch *Bothriochloa pertusa*) that can impede planned burns.

Many of these species are promoted by fire, and promote fire (Plates 3.28–3.30). Prevention and early intervention and integrated control techniques are critical.

Control techniques other than or coupled with fire, such as herbicide and/or strategic grazing, will be required where high-biomass weed species are established. Burning these areas, without integrated control, causes ongoing degradation.

Plate 3.28 (above) A bushfire fuelled by the ecosystem-changing weed buffel grass *Cenchrus ciliaris* resulted in the death of many gidgee *Acacia cambagei* in this fire-sensitive community, Mazeppa National Park.
Photo: Rhonda Melzer © Qld Govt.

Plate 3.29 (right) Dense patches of the ecosystem-changing weed lantana *Lantana camara* acted as a wick, drawing high-intensity bushfire into fire-sensitive deciduous vine thicket and leading to the death of many trees, including emergent bottle trees, Forty Mile Scrub National Park.
Photo: John Clarkson © Qld Govt.

3—The role of fire in species and ecosystem conservation

Plate 3.30 Frequent fire when the ecosystem-changing weed grader grass *Themeda quadrivalvis* is present can create dense infestations that seriously compromise conservation values, Rinyirru (Lakefield) National Park (CYPAL) 2004. *Photo: John Clarkson © Qld Govt.*

Surveillance for new or expanding weed infestations is integral to post-fire assessment and early intervention.

Planned burns can be used in integrated weed management programs (Plate 3.31), including for vines, such as rubber vine *Cryptostegia grandiflora*, woody weeds and high-biomass grasses. Planned burning can help:

- facilitate access
- kill mature weeds
- eliminate a crop of weed seed by burning before seed fall
- promote germination of soil-stored seeds (e.g. leucaena *Leucaena leucocephala*) so juvenile plants can be sprayed or burnt before reaching sexual maturity
- reduce weed vigour and dominance
- promote fresh growth that is more susceptible to herbicide (e.g. lantana *Lantana camara*).

Understanding the life cycle of the weed species, including the longevity of soil seed banks, is critical to determining the fire regime and specific burn conditions and timing (season) that support weed management efforts.

Plate 3.31 Results of a control program, integrating herbicide treatment, planned burning and stock removal for the ecosystem-changing weeds lantana *Lantana camara* and sicklepod *Senna obtusifolia* in endangered poplar gum *Eucalyptus platyphylla* open forest. Fire was used after the initial herbicide treatment to remove standing dead weeds. Fire was also used in subsequent years to promote synchronised sicklepod germination for spraying and to encourage native grasses. Within four years, the understorey changed from >95% to <5% weed cover and >95% native grasses, Henrietta Creek, Girringun National Park:
a. pre-treatment, April 2008; **b.** August 2010; **c.** July 2020.

Photos: Mark Parsons © Qld Govt.

Additional information

Bioregion-specific weed issues relevant to fire management are addressed in the bioregional guidelines.

Strategic response to invasive and high biomass grasses:

Clarkson 2020, *Management of invasive and high biomass grasses on QPWS managed lands*. (internal)

Melzer 2015, 'When is stock grazing an appropriate 'tool' for reducing *Cenchrus ciliaris* (buffel grass) on conservation reserves?', *Proceedings of the Royal Society of Queensland*, vol. 120, 53–68.

3.2.4 Fire and plant pathogens

Some plant pathogens that impact native species and ecosystems can increase after fire. Fire should rarely be excluded from fire-adapted ecosystems that are susceptible to these pathogens. However, it is important to be aware of signs of infection and any biosecurity and other protocols in pest and fire strategies to minimise risk and reduce impacts.

Mosaic burning may help reduce the vulnerability of plant populations to severe pathogen impacts by reducing the likelihood of broadscale bushfire and the associated stress on vegetation.

Two of the more significant plant pathogens are myrtle rust and *Phytophthora cinnamomi*.

Myrtle rust

Myrtle rust is a fungal disease caused by the introduced *Austropuccinia psidii*. Myrtle rust affects species in the family Myrtaceae (Plate 3.32). It is now widespread in the humid northern and eastern parts of the mainland and Tasmania.

The spores are easily dispersed by wind and on animals and humans. Myrtle rust particularly affects new leaves and shoots, causing dieback and, in severe cases, death. Seedlings are highly susceptible. The spores can also infect flowers and fruits, making plants infertile.

Myrtle rust can significantly impact post-fire regeneration of vegetation, including dominant species, such as swamp paperbark *Melaleuca quinquenervia* and prickly leaf paperbark *M. nodosa*.

The potential for controlling myrtle rust in natural environments is extremely low. Monitoring and research in parks and forests will contribute to understanding species' susceptibility, with respect to fire and fire regimes, and may help develop interventions. Avoiding canopy scorch in planned burns may help minimise myrtle rust impacts.

Plate 3.32 Myrtle rust infection on post-fire resprouts of the critically endangered scrub turpentine *Rhodamnia rubescens,* Mount Barney National Park, May 2020:
a. early-stage infection (yellow spots); **b.** late-stage infection showing extensive leaf shrivelling and death.
Photos: Harry Hines © Qld Govt.

Phytophthora

Phytophthora cinnamomi is a soil-borne pathogen that causes dieback in susceptible plant species (Plate 3.33). It is readily spread in soil or by surface or subsurface water movement. Dieback is most common when there is free water, warm temperatures and neutral to acidic soils.

There is some evidence that fire may increase the severity and extent of the disease in native plant communities where post-fire conditions are more open, moister, and warmer than usual and susceptible species are stressed.

It is usually impossible to eradicate *Phytophthora* from an infected area. Quarantine and containment procedures are the primary means to manage the threat. These should be included in a pest strategy and inform fire management tactics.

Additional information

Myrtle rust:

Fensham & Radford-Smith 2021, 'Unprecedented extinction of tree species by fungal disease', *Biological Conservation*, vol. 26.

Makinson 2018, *Myrtle rust reviewed: the impacts of the invasive plant pathogen Austropuccinia psidii on the Australian environment*.

Makinson et al. 2020, *Myrtle rust in Australia – a national action plan*.

Pegg et al. 2021, *Fire and rust – impact of myrtle rust on post-fire regeneration*.

***Phytophthora*:**

Commonwealth of Australia 2018a, *Threat abatement plan for disease in natural ecosystems caused by Phytophthora cinnamomi*.

Commonwealth of Australia 2018b, *Background document: threat abatement plan for disease in natural ecosystems caused by Phytophthora cinnamomi*.

Moore et al. 2014, 'Time since fire and average fire interval are the best predictors of *Phytophthora cinnamomi* activity in heathlands of south-western Australia', *Australian Journal of Botany*, vol. 62, 587–593.

Plate 3.33 This population of *Macrozamia miquelii* has largely been eliminated as a likely consequence of *Phytophthora*. *Photo: © Rhonda Melzer.*

3.3 Guiding principles and practices for ecological burning

Most Queensland ecosystems and species have adaptations to survive fire, or regenerate or recolonise following fire. However, a wide range of factors can influence the outcomes of a fire and fire regimes (sections 3.1 and 3.2)

A single fire-adapted ecosystem can contain species with a spectrum of responses and tolerances to fire. For example, a community may include relatively immobile fauna species with specialised diets and highly mobile species with broad dietary requirements.

Some species are considered generalists, persisting under a wide range of non-extreme fire regimes. Their abundance may fluctuate, but they remain widespread across ecosystems and landscapes.

Other species are specialists, only persisting in habitats created by a particular fire regime or where fire management practices ensure critical habitat persists or provides long unburnt habitat. Some require resources from across a suite of vegetation age-classes.

For many specialist or threatened species in fire-adapted landscapes, knowledge of fire regime requirements is limited.

There is much to learn about managing species and ecosystems with fire, particularly with a changing climate (section 4). However, the following principles and practices will help guide the planning and implementation of ecological burns.

1. Well-planned and implemented fire management is essential to the maintenance of healthy fire-adapted ecosystems and the protection of fire-sensitive communities. Healthy ecosystems, in turn, contribute significantly to conserving many species. The bioregional guidelines focus on this principle.

Fire needs to be actively managed, not excluded, to maintain or protect ecosystem, habitat and species diversity.

2. Spatial and temporal variation in fire regimes (mosaic burning) within ecosystems and across landscapes produces heterogeneous (diverse) habitat and facilitates the coexistence of species with different life history strategies. Mosaic burning (see Box 3.1 and Appendix 3) is foundational to fire management for ecological purposes.

   Understanding the response of fauna, especially threatened species, to spatial and temporal mosaics including the required size and distribution of various aged patches will take time. Bradstock et al. (2012) provide a thought-provoking discussion on the topic. Information from ecological burn programs and fire history mapping can help fill these knowledge gaps.

For some species, the benefits of planned burning are due to the maintenance of long unburnt patches rather than the provision of resources in burnt areas.

3. Fire-sensitive habitat and other values should be protected within the landscape mosaic (e.g. springs, semi-evergreen vine thicket, fire-sensitive *Acacia* communities, such as brigalow *A. harpophylla*, gidgee *A. cambagei*, Georgina gidgee *A. georginae*).
4. Long unburnt and old-growth fire-adapted habitat should be retained within the mosaic. This is not achieved by withdrawing burning from the landscape nor by relying on bushfire response. It typically requires active fire management including, at least in some landscapes, the frequent application of planned burns (section 5, case study 5.1). The aim is to increase the proportion of older age-classes within the landscape by reducing the risk of widespread, damaging bushfires.
5. Ensure fire management does not lead to ecosystem transformation (e.g. grassland to woodland, woodland to rainforest) unless there is a purposeful, documented intent to do so (e.g. to create habitat for a threatened species).
6. Ensure fire management does not lead to widespread or long-term decline or permanent loss of critical habitat features (e.g. logs, hollow-bearing trees, shrub layers, complex litter beds) or functions (e.g. recruitment of canopy species).

Approximately 300 Australian native vertebrate species rely on hollow-bearing trees in part of their life cycle. At least 95 of these species occur in Queensland.

Hollow-bearing trees may be many hundreds of years old and are essentially irreplaceable. They are now scarce in many areas because of timber harvesting and/or fire.

7. Ecosystems and landscapes should not have high proportions of young age-classes and small proportions of old age-classes.
8. Fire intervals should lengthen with decreased ecosystem and landscape productivity. For example, habitats in arid areas with poor soils regenerate slowly and require longer fire intervals than those on better soils and/or in areas of higher rainfall.
9. Fire strategies and burn plans should include any specialist requirements of threatened species that occur in fire-adapted habitats. The means to monitor these species and evaluate fire management outcomes should be captured in the monitoring and research strategy. Detailed fire mapping (section 2.3) is invaluable for better understanding the relationship between threatened species, their habitat and fire regimes.
10. Identify species with characteristics that make them most susceptible to decline under the fire regimes that might be applied to an ecosystem. Monitoring these provides a means to validate success in achieving biodiversity conservation by focusing on a few indicators. A suitable indicator species must be reasonably detectable using an appropriate monitoring methodology.
11. Where possible, integrate pest and fire management activities to achieve more effective outcomes.

Gaps in knowledge are not a reason to avoid burning.

Plan and implement burns based on existing information, record the outcomes and learn from them.

Recording and sharing knowledge and observations are critical parts of fire management and can help bridge knowledge gaps.

Box 3.1 Mosaic burning

Mosaic burning, at the ecosystem and landscape scale, is the use of planned burns to create a patchwork of areas of varying post-fire ages, burnt at various frequencies, intensities and in varying seasons within the tolerance of the ecosystems. It takes into consideration the impact/contribution of bushfires.

Mosaic burning includes creating patchiness within burns including burnt and unburnt patches and variation in intensity within the former.

The goal of mosaic burning is not to create a static 'jigsaw' of interlocking 'pieces', with each 'piece' representing 'time since fire' (for example), such as might be achieved with uniform block burning. The goal is to create an increasingly complex and varied (heterogenous) pattern over time. This pattern includes:

- visible mosaics (burnt and unburnt patches in individual burns)
- invisible mosaics as portions of burns overlay each other.

A simple example is provided in Appendix 3.

It is important to retain as many, and as large, long unburnt and old-growth patches as possible in the mosaic without increasing the risk of widespread and damaging bushfires.

Increased heterogeneity within the landscape burn mosaic (pyrodiversity) does not necessarily equate to increased species diversity in highly fire-adapted ecosystems. This is because many species in these ecosystems are resilient to a range of fire regimes. Nevertheless, a diverse mosaic that includes relatively long unburnt refugia offers a spectrum of wildlife habitat and creates landscape resilience to events like bushfire and drought.

A well-developed mosaic reduces the need to rely on constructed fire lines. While sometimes necessary, these increase the risk of pest species invasion and erosion, and create barriers to movement for some native species.

See section 5.4.1 for implementing mosaic burning.

Additional information

Bradstock et al. 2012, 'Future fire regimes of Australian ecosystems: new perspectives on enduring questions of management', in Bradstock et al. eds., *Flammable Australia: fire regimes, biodiversity and ecosystems in a changing world*.

DAWE 2022 Fire regimes that cause declines in biodiversity as a key threatening process. (external)

Species reliant on tree hollows:

Gibbons & Lindenmayer 2002, *Tree hollows and wildlife conservation*.

Lamb et al. 1998, *Managing habitat trees in Queensland forests*.

Pyrodiversity and biodiversity:

Jones & Tingley 2021, 'Pyrodiversity and biodiversity: a history, synthesis, and outlook', *Diversity and Distributions*, vol. 29, issue 3, 1–18.

Value of old-growth habitat:

Andersen 2021, 'Faunal responses to fire in Australian tropical savannas: Insights from field experiments and their lessons for conservation management', *Diversity and Distributions*, vol. 27, issue 5, 828–843.

DEC 2004 *Old growth forests*. (external)

Low 2011, *Climate change and terrestrial biodiversity in Queensland*.

Mackey et al. 2012, 'Ecosystem greenspots: identifying potential drought, fire and climate-change micro-refuges', *Ecological Applications*, vol. 22, 1852–1864.

Moran & Boulter 2018, *Biodiversity and ecosystems climate adaptation plan*.

Plate 3.34 The ground orchid *Pterostylis scoliosa* (endangered) is known from a couple of locations in D'Aguilar National Park. It grows from tubers with plants emerging mid-late summer, depending on rains, to flower in the period March to May. New plants growing from seed can take a few years to mature. Plants have a dormant period from around August to early January. Fire over a colony of this species during the growing cycle (mid-late January to June/early July) will have a detrimental effect, possibly catastrophic, on the reproductive success of the species and should be avoided. After a fire, a colony should not be burnt again for at least five to seven years to ensure population stability *Photo: Michael Mathieson © Qld Govt.*

4 Fire and climate change

Queensland is already experiencing the impacts of climate change, with average annual temperatures rising since 1910. The greatest recorded increase in annual average maximum temperature in the period between 1950 and 2018 was over 2°C. It occurred in southwest Queensland. The number of days with dangerous fire weather conditions has increased in most locations across the state. The greatest increases in the Forest Fire Danger Index (FFDI) occurred in southeast Queensland.

Climate projections for Queensland include:

- higher maximum, minimum and average temperatures
- more frequent hot days
- longer hot periods.

The effect of climate change on rainfall patterns is less clear. High climate variability is likely to be the major influence on rainfall for the next few decades. In southern Queensland there has been a trend towards lower rainfall throughout the year. This has been particularly evident over the last decade.

The number of cyclones is projected to decrease but they are likely to be more intense and move further south. Extreme rain events are projected to become more intense. Both wetter and drier futures are possible in monsoonal areas.

The influence of climate change on the frequency and duration of drought is uncertain. In general, Queensland is likely to become drier in the period from May to October. Moisture deficits (drought-like conditions) will come on more quickly with increasing temperatures.

Trends and projected future changes for severe thunderstorms, dry lightning (lightning that occurs without significant rain) and strong winds are highly uncertain. Some recent research suggests the frequency of severe convective wind environments may increase in spring, summer and autumn, particularly in western Queensland. Analysing potential fire behaviour and managing bushfire will be more complex in those environments.

Despite uncertainties around how climate change will affect some weather and climate factors, Queensland is likely to experience increased numbers and longer sequences of severe (extreme and catastrophic) fire weather days. There will be less likelihood of conditions easing during the night. More days each year are likely to reach or exceed extreme fire danger. Ignitions from dry lightning may increase.

Where extreme weather and climate events coincide or follow each other within a short time frame, the severity of the impacts can be compounded (see Box 4.1). Already, bushfire seasons are generally starting earlier and lasting longer. This pattern is expected to continue.

Box 4.1 Compound extreme events (extract from State of the Climate 2020)

Climate change influences the frequency, magnitude and impacts of many extreme weather and climate events.

Extreme events are more likely when natural climate variability amplifies the background influence of climate change. For example, record-breaking extreme heat and fire weather are more likely when the El Niño–Southern Oscillation or the Indian Ocean Dipole favour warmer and drier conditions in Australia, since this reinforces warming and drying trends.

When extreme weather and climate events coincide or follow each other within a short time frame, the severity of the impacts can be compounded. For example, heatwaves can have a greater impact when combined with the stress of long-term drought.

The spring and early summer of 2019 is a good example of compounding extreme weather and climate conditions, showing how background climate trends amplify natural climate variability. In this period, record-breaking low rainfall coincided with extreme heat and continued into early 2020. An extreme positive Indian Ocean Dipole and rare Antarctic stratospheric warming in 2019 provided the naturally occurring climate variability that exacerbated long-term climate change trends. These combined influences led to severe drought, record-breaking heatwaves and fire weather.

Natural climate variability affects Australia's climate from one year to the next. This means weather and climate will not always be as extreme as in 2019. However, the warming trend, primarily caused by climate change, increases the likelihood of extreme events that are beyond our historical experience. Multiple lines of evidence, including observations and future climate change projections, point to a continuing trend of more-frequent compound extreme events.

Additional information

QFES Queensland Bushfire Plan: https://www.disaster.qld.gov.au/cdmp/Documents/QLD-Bushfire-Plan.pdf

Climate Change in Australia 2022, Queensland's changing climate. https://www.climatechangeinaustralia.gov.au/en/changing-climate/state-climate-statements/queensland/

Commonwealth of Australia 2019, *Changes to fire weather in Queensland*. (Examines changes in fire weather conditions from 1950-2018 for the state and separately for nine subregions)

Commonwealth of Australia 2020, *State of the climate 2020*.

Commonwealth of Australia 2022, *State of the climate 2022*.

Dowdy et al. 2021a, *Extreme temperature, wind and bushfire weather projections using a standardised method*.

Dowdy et al. 2021b, *Extreme bushfire projections for Australia using a standardised method*.

Spassiani 2020, *Climatology of severe convective wind gusts in Australia*.

Syktus et al. 2020, *Queensland Future Climate Dashboard: downscaled CMIP5 climate projections for Queensland*. (Provides climate projections for specific areas in Queensland (e.g. local government, bioregions) using the most recent model outputs and simulations. Detailed help is provided to the reader to interpret the data). https://www.longpaddock.qld.gov.au/qld-future-climate

4.1 Climate change, fire regimes and biodiversity

Ongoing climate change will continue to alter fire regimes through its influence on:

- the components of fire weather (e.g. temperature, rainfall, humidity, wind, drought, heatwaves)
- vegetation growth and fuels due to increased atmospheric CO_2 and changes in moisture (e.g. canopy thinning due to increased temperatures and drying will reduce moisture in the understorey and litter layer).

Predicting some changes that relate to fire management may be difficult. For example, elevated CO_2 may increase vegetation growth and so fuel loads, but drier conditions may have the opposite effect by causing a decrease in productivity and fuel accumulation rates.

The response of species and ecosystems to the interactions between climate change and fire regimes will also be complex, varied and difficult to predict. There have been, and increasingly will be, undesirable biodiversity outcomes because of climate change and associated changes to fire regimes.

There will be feedback loops with negative outcomes. For example, climate change may facilitate invasion by weed species that increase fuel loads and, in turn, exacerbate the effects of climate change on fire regimes.

Large fires are part of Australian fire regimes and are part of the historical range of variability for most of the country. In the context of climate change and biodiversity, it is not so much the occurrence of an individual large fire but the rate of recurrence (i.e. fire interval) and time for regeneration that poses the significant additional risk.

4.1.1 Climate change and the key drivers of fire regimes

Fire regimes differ across Queensland because of variations in four key drivers, regardless of climate change. The drivers are:

- biomass/fuel accumulation (load, type and arrangement)
- availability of fuel to burn (moisture content)
- fire weather
- ignition sources.

Understanding how these drivers vary across ecosystems in parks and forests will help determine how climate change may influence fire regimes (see Box 4.2 The Four Switch Model). Climate change will likely affect fire regimes more in places where bushfire events have historically been limited by the occurrence of severe fire weather at the same time fuels are dry.

Box 4.2 The Four Switch Model

(see Williams et al. 2009 and Bradstock 2010 for detailed discussion)

Patterns in fire regimes in Australia reflect variations in four key drivers, regardless of the ecosystem.

1. **Biomass/fuel accumulation**
   The quantity and type of fuel depend on the vegetation type and productivity or growth rate which in turn depend on moisture availability and soil type.
2. **Availability of fuel to burn**
   This depends on the fuel moisture content. Different areas experience prolonged dry periods over different time frames (e.g. annually through to decadal or longer).
3. **Occurrence of fire weather** (weather suitable for fire to spread, in particular, high wind speed, low humidity and high temperature).
4. **Ignition sources** (e.g. lightning or human)

The four drivers can be thought of as switches. These switches must all be turned 'on' at the same time for fire to occur. They also influence the rate and extent of fire spread.

Ecosystems vary in how often switches are 'off' or 'on'. This variation results in different fire regimes.

Understanding the switches for ecosystems helps in understanding how climate change may influence fire regimes and so helps determine the best management approaches.

For example, in northern tropical grassy open forests, three of the switches are 'on' every annual dry season:

- switch 1: there is plenty of fuel due to high productivity (in particular, grass growth) during the wet season.
- switch 2: fuel is available to burn because fuel moisture is low.
- switch 3: weather is conducive to fire spread (e.g. low humidity, high temperatures).

In this case, the occurrence of fire is limited by ignition sources (switch 4). Climate change is unlikely to alter this scenario, apart from increasing lightning strikes, so it may not have a major effect on fire frequency or the area burnt. This means fire management practices that currently benefit biodiversity conservation may continue to be applicable (see case study 5.1).

In contrast, tall wet eucalypt forests typically have plenty of fuel (switch 1 is always 'on' except after a fire) but the fuel is often too moist to burn (switch 2 is often 'off'). Fire weather (switch 3) and ignition source (switch 4) may also limit the occurrence of fire. In this case, the projected increase in extreme fire danger days, heatwaves and perhaps droughts in Queensland, is likely to increase fire frequency, intensity and the area burnt. This is because switches 2 and 3 will be 'on' more often. Using staged or progressive burning, and taking advantage of rainfall events, is likely to become more important (see case study 5.2).

Additional information

Historic large-scale bushfires:

Bradstock et al. 2002, *Flammable Australia: the fire regimes and biodiversity of a continent*.

Williams et al. 2009, *Interactions between climate change, fire regimes and biodiversity in Australia – a preliminary assessment*.

Wright et al. 2021, 'Rainfall-linked megafires as innate fire regime elements in arid Australian spinifex (*Triodia* spp.) grasslands', *Frontiers in Ecology and Evolution*, article 666241.

Climate change and planned burning:

Clarke et al. 2019, 'Climate change effects on the frequency, seasonality and interannual variability of suitable prescribed burning weather conditions in south-eastern Australia', *Agricultural and Forest Meteorology*, vol. 271, 148-157.

The Four Switch Model:

Bradstock 2010, 'A biogeographic model of fire regimes in Australia: current and future implications', *Global Ecology and Biogeography*, vol. 19, 145–158.

Williams et al. 2009, *Interactions between climate change, fire regimes and biodiversity in Australia – a preliminary assessment*.

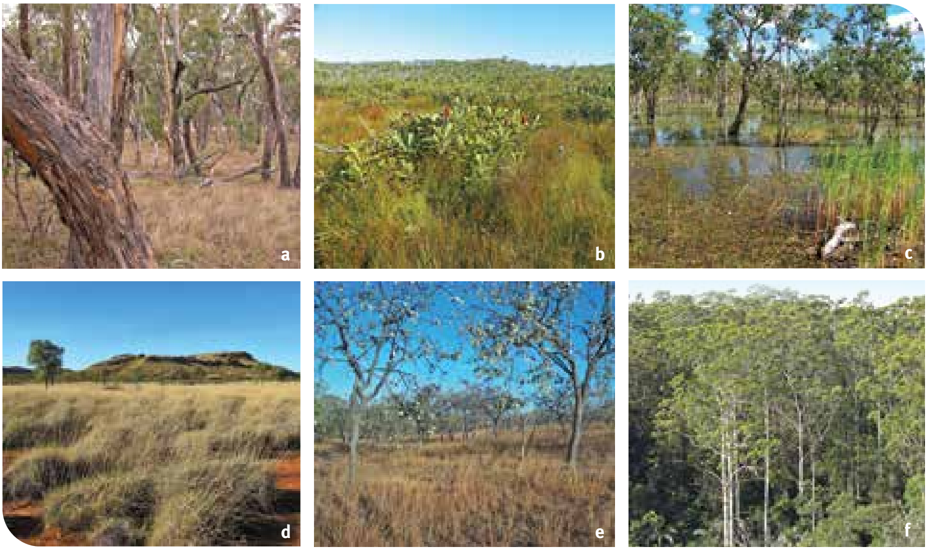

Plate 4.1 Examples of ecosystems varying in the drivers determining fire regimes:

- **a.** yellow box *Eucalyptus melliodora* and gum-topped box *E. moluccana* open forest, New England Tableland Bioregion. *Photo: Annie Kelly © Qld Govt.*
- **b.** swamp banksia *Banksia robur* wet heath, Great Sandy National Park, South East Queensland Bioregion. *Photo: Rhonda Melzer © Qld Govt.*
- **c.** broad-leaved paperbark *Melaleuca viridiflora* low woodland on a lagoon, Staaten River National Park, Gulf Plains Bioregion. *Photo: Gary Wilson © Qld Govt.*
- **d.** giant grey spinifex *Triodia longiceps* hummock grassland, Northwest Highlands Bioregion. *Photo: Dan Kelman © Qld Govt.*
- **e.** silver-leaved ironbark *Eucalyptus shirleyi* low open woodland, Einasleigh Uplands Bioregion. *Photo: Mark Newton © Qld Govt.*
- **f.** flooded gum *Eucalyptus grandis* tall open forest, Southeast Queensland Bioregion. *Photo: VJ Neldner © Qld Govt.*

4.2 Adapting ecological burning to climate change

Complex interactions and feedback loops make the rate and direction of change in ecosystem composition, structure and function difficult to predict. This makes it more important than ever to use an evidence-based adaptive management approach (see Box 4.3).

The key natural values, including threatened species at risk from climate change, will be identified in VBMF planning instruments (e.g. values assessments) and thematic strategies. Fire and pest strategies will include actions to mitigate impacts and facilitate adaptation or resilience. Monitoring and research needs will be identified in monitoring and research strategies and the QPWS research prospectus. Objectives and guidelines for burning must be reviewed and modified over time considering contemporary climate data, monitoring and research.

Partnerships with First Nations people and collaboration with other fire management agencies, land managers and research organisations will be increasingly important.

Despite the uncertainty posed by climate change, the principles and practices outlined in sections 3.3 and 5 remain sound. Managing for ecosystem health and resilience and habitat diversity and complexity amongst ecosystems and across landscapes, can help minimise ecosystem decline and species loss. This includes:

- avoiding burning at times that will add significant stress to communities (e.g. during dry periods and drought)
- addressing interacting threats, particularly those that elevate the risk of increased fire intensity and frequency (e.g. the invasion of high-biomass weeds)
- mitigating the extent, frequency and intensity of bushfires to minimise impacts on biodiversity.

There will always be a residual risk of bushfire. The approach to minimising bushfire risk should not be worse for biodiversity outcomes than the risk itself.

Identifying and prioritising management of climate refugia (e.g. cooler, moister habitats like gorges, springs and vegetation communities on fractured rock aquifers) is increasingly important. Similarly, long unburnt patches and old growth are likely to become more scarce and increasingly valuable refuges as the climate changes. Protecting critical habitat features, such as hollow trees and logs, is important because they provide refuge from high temperatures.

Maintaining grasslands and grassy woodlands and open forests may require more attention and effort because of woody weeds and woody thickening by native species. Woody thickening by natives occurs as part of natural ecosystem recovery and can also be triggered by changes in land management practices. However, woody thickening, whether by weeds or native species, is enhanced by the effects of climate change, such as elevated atmospheric CO_2.

Climate change will increasingly affect the number and seasonal distribution of days that are suitable to burn. It will be imperative to be alert to the conditions required to achieve the desired outcomes of fire strategies and burn plans and make the most of opportunities when they arise. Opportunities for burning can be extended by implementing staged burning (section 5.4.2).

Be alert to the conditions required to achieve desired outcomes and make the most of opportunities when they arise.

Box 4.3 Adaptive management approach

The Council of Australian Governments' National Bushfire Inquiry (Ellis et al. 2005) outlined what an adaptive management approach should include to ensure fire management supports biodiversity conservation, despite incomplete knowledge and uncertainty.

Key recommendations from this inquiry are increasingly relevant with ongoing climate change:

- explicitly state the biodiversity objectives
- recognise lack of knowledge and clarify questions that need to be answered
- design burning that will enable these questions to be answered
- devise and fund monitoring and other data collection
- review and communicate results
- use the new knowledge to modify the management prescription.

Additional information

Prioritising climate refugia:

Low 2011, *Climate change and terrestrial biodiversity in Queensland*.

Mackey et al. 2012, 'Ecosystem greenspots: identifying potential drought, fire and climate-change micro-refuges', *Ecological Applications*, vol. 22, 1852–1864.

Moran & Boulter 2018, *Biodiversity and ecosystems climate adaptation plan*.

Adaptive management approach:

Ellis et al. 2005, *National inquiry on bushfire mitigation and management*.

Woody thickening:

Macinnis-Ng & Eamus 2009, *The increasing density of shrubs and trees across a landscape*.

Manea & Leishman 2019, 'The resprouting response of co-occurring temperate woody plant and grass species to elevated CO2: an insight into woody plant encroachment of grasslands', *Austral Ecology*, vol. 44, 917–92.

Plate 4.2 Swamp banksia *Banksia robur* and swamp grasstree *Xanthorrhoea fulva* low shrubland on patterned fens. These ecosystems are highly fire-adapted providing burns occur when the peat is saturated, K'gari (Fraser Island) Great Sandy National Park.
Photo: Andrew Meiklejohn © Qld Govt.

Plate 4.3 Climate refugia such as springs are increasingly important with climate change. Bunbuncundoo Springs, Ka Ka Mundi, Carnarvon Gorge National Park.
Photo: Robert Ashdown © Qld Govt.

5 Planning, implementing and evaluating ecological burns

Fire management for ecological purposes follows the adaptive management approach – learning, planning, implementing, monitoring, and evaluating to inform future management.

5.1 Guiding principles for ecological burning

Managing biodiversity within parks and forests involves active and ongoing management of fire. This is not a simple task. The way ecosystems and species respond to fire regimes is complex, and climate change brings additional challenges.

However, there are key principles and practices to guide planning, implementing and learning from burns that will help achieve biodiversity conservation goals. These are discussed in section 3.3 and elsewhere in this volume. They are summarised here. Adopting these should achieve good ecological outcomes.

1. Maintain healthy ecosystems including critical habitat features such as logs and hollow-bearing trees.
2. Aim for spatial and temporal variation in fire regimes, including patchiness in individual burns (see Box 3.1 and Appendix 3).
3. Create and/or maintain long unburnt and old-growth patches, as the habitat they provide is fundamentally important to the survival and/or recovery of some species.
4. Identify and monitor species with characteristics that make them most susceptible to decline under the fire regimes that might be applied to an ecosystem.
5. Be flexible with the burn program, to respond to and potentially take advantage of changed circumstances, including bushfires and other disturbances.
6. Address interacting threats such as grazing, predation and/ or weed invasion (see section 3.2).

Burning for ecological purposes plays a significant role in reducing bushfire risk and impacts.

5.2 Learning about the park or forest

Good knowledge of a park or forest is essential when planning and implementing fire management. The history of fire and other disturbances, local ecosystem and landscape characteristics including fuel types and dynamics, key values and desired biodiversity outcomes must be considered for effective ecological fire management.

Building this knowledge takes time spent on the park or forest being curious and observant. There are also several valuable sources of information described here.

- The VBMF values assessment, management plan or statement, and strategies including the fire strategy and pest strategy. They are fundamental resources and are informed by the other resources described here.
- The relevant bioregional guideline/s for the park or forest. They provide the foundation for recognising, and maintaining or recovering, healthy vegetation communities through fire management.
- The Regional Ecosystem Description Database (REDD) for guidance on fire regimes for individual regional ecosystems.

Local context is critical when applying guidelines.

For example, maritime conditions may mean the fire regime and/or burn conditions suited to a regional ecosystem on the mainland are not suited to the same ecosystem on an island.

- Regional Ecosystem (RE) mapping. This is invaluable for fire planning, implementation and reporting. The scale of RE mapping may not capture small but important patches of vegetation (e.g. springs/soaks, pockets of rainforest, montane heath, lancewood) or finer-scale patterns relevant to fire management. Local knowledge is essential to identifying and considering these in the fire strategy.

RE mapping is available statewide, at a scale of 1:100 000 or 1:50 000, and finer scales for Brisbane City Council area and some islands.

Broad vegetation groups (BVGs) are a higher-level grouping of REs. They provide an overview of ecological patterns and relationships in the vegetation, independent of bioregions. The REs that comprise BVGs at the 1M scale, usually have similar fire regime requirements.

- The VBMF Standard Report provides RE and BVG maps and descriptions, lists of significant taxa recorded in the park or forest and modelled potential habitat for significant species that occur or are predicted to occur there. Instructions for generating a report are provided in Appendix 2. WildNet, WildMap and RE mapping are the primary data sources for the report.
- The *Overall Fuel Hazard Assessment Guide*. Use the guide to assess fuel hazards across the landscape, in different seasons and at different times since fire. This will help in understanding how fuel type, arrangement and accumulation vary.

While the bioregional guidelines and REDD provide fire management guidelines for vegetation communities, there are no similar centralised guidelines for Queensland species. Information can be sourced from:

- scientific papers, reports, theses and action and recovery plans held in WildNet
- scientific papers accessible through tools like Google Scholar and the department's Library Services
- the Australian Government's Species Profile and Threats Database
- internal and external experts involved in species research and monitoring.

Case studies 3.1-3.5 highlight some examples of information sources available for significant fauna species.

Additional information

Falster et al. 2021, 'AusTraits, a curated plant trait database for the Australian flora'. *Scientific Data*, vol 8, article 254.

Modelled potential habitat for threatened species:
Laidlaw & Butler 2021, *Potential habitat modelling methodology for Queensland*.

Regional Ecosystems and Broad Vegetation Groups:
Regional Ecosystem Description Database (REDD) (external)
Neldner et al. 2021, *The vegetation of Queensland. Descriptions of Broad Vegetation Groups*.

Overall Fuel Hazard Guide:
Hines et al. 2010, *Overall Fuel Hazard Assessment Guide*. (external)

Australian Government's Species Profile and Threats Database:
https://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl

5.3 Planning the burn program

The fire strategy for the park or forest establishes the strategic management directions for fire management and associated objectives. It is informed by several documents (see Box 1.2) and the BRMF (section 1.2.2). The objectives identified in the fire strategy inform decisions about the burns (e.g. timing, section 5.4.2 and tactics, section 5.4.3) and fire regimes that will be required, including for managing risk and values.

A fire strategy is implemented over several (5–10) years, through a program of planned burns.

When planning burns, consider questions such as:

1. Are there adequate protections for fire-sensitive assets (e.g. infrastructure, cultural heritage places) so that burns can be readily implemented in adjacent areas?
2. Are there fire-sensitive ecosystems that require protective measures, such as early dry season low-intensity burns, so that ecological burns can be readily implemented in adjacent areas?

3. Are there fire-adapted ecosystems that need to be excluded from fire for a period to ensure sufficient regeneration (e.g. immature lancewood *Acacia shirleyi* or recently burnt montane heath)?
4. Are there fire-adapted ecosystems that have particular requirements (e.g. saturated soil during planned burns to prevent peat loss in peat swamps)?
5. Are there priority old-growth patches or maturing patches (future old growth) that need protection?
6. Are there high-priority species that require specific fire regimes or specific outcomes from fire management (e.g. retention of hollow-bearing trees, unburnt patches of a minimum size, seed germination (see case studies 3.1–3.5))?
7. What precautions and/or post-fire response may be required to prevent invasion of the burnt area by ecosystem-changing weeds?

Ensure that appropriate consultation occurs with First Nations people, neighbours, stakeholders and local Bushfire Management Groups when planning the burn program.

Remember!

- Plan to provide unburnt patches within each burn, particularly if a whole ecosystem is within the burn extent (section 3.3). It can be difficult to retain unburnt patches in small, isolated patches of an ecosystem. In these circumstances, the aim should be to retain refuges (e.g. woody debris, grass/sedge bases).
- Plan to promote variation in fire regimes over time and space. This includes maintaining or, if appropriate, increasing the amount of habitat burnt at the upper end of the fire interval recommended for the ecosystem.

5.3.1 Measurable objectives

For planned burning to be an effective conservation management tool, objectives should be meaningful and measurable. This will allow evaluation of progress towards short- and long-term goals.

Objectives should be SMART:

- **S**pecific
- **M**easureable
- **A**ttainable
- **R**elevant
- **T**ime-based.

A fire strategy sets strategic management directions with associated objectives. Some examples are provided in Table 5.1. In these examples, the SMART objectives are based on QPWS Health Check criteria, to ensure that outcomes are measurable and ecologically relevant.

Table 5.1 Examples of strategic management directions in fire strategies with objectives (sometimes coupled with objectives in pest strategies) based on QPWS Health Check criteria (Melzer 2022).

Abbreviations:
G – good; GC – good with some concern; SC – significant concern; C – critical.

Strategic management directions (SMD)	Objectives
Restore the structural age-class distribution in *Eucalyptus tereticornis* open forest across the park.	The alignment to ecological requirements of the fire age-class improves from 'inadequate' (SC) to 'close/reasonable' (GC) by 2030 and to 'very close' (G) by 2035 (Health Check criterion 14b). The level of recruitment of canopy species improves from 'may not be sustainable' (SC) to 'probably sustainable' (GC) by 2035.
Restore *Eucalyptus grandis* open forest structure.	Reduce the level of rainforest invasion from 'moderate' (SC) to 'light' (GC) (Health Check criterion 4) by 2030 and to 'rare' (G) by 2035.
Maintain habitat of endangered reptile in *Eucalyptus crebra* woodland.	Key features for faunal biodiversity (Health Check criterion 19) are G or GC at sites and no worse than GC for the General Impression.
Maintain extent and condition of semi-evergreen vine thicket.	Condition class for Health Check criterion 12 (fire damage to fire-sensitive ecosystems) is G at all sites and for the General Impression. Ecosystem-changing pest plants are absent (G) or 'inconspicuous' (GC) at all sites and no worse than GC for the General Impression.
Restore the condition of the moist to dry eucalypt open forests.	Reduce the *Lantana camara* infestation from 'dominant' (C) to 'conspicuous' (SC) by 2025 and 'inconspicuous' (GC) by 2030 (Health Check criterion 1) at priority locations A, B and C.

Objectives of a fire strategy will typically be met through the implementation of a program of burns over several to many years (see Box 5.1). However, in some cases an individual burn may fulfil one or more objectives for the period of the current fire strategy.

Each burn will have its own objectives (burn-specific objectives). These are documented in the burn proposal and fire report in FLAME. They provide steps to achieving the longer-term objectives of the fire strategy and therefore the strategic management direction/s. Examples of burn-specific objectives are provided in each of the bioregional guidelines, and here in Boxes 5.1 and 5.2.

Where possible, fire strategies and burn plans should include objectives that allow the effectiveness of fire management in achieving outcomes for key species to be examined. For example, if an endangered plant species occurs within a fire-adapted ecosystem, a simple objective may be for no population decline. This is measurable, and when coupled with information on fire history and the species' response to fire, will contribute to knowledge of the species' ecology and its future management.

The means to evaluate and report on objectives are discussed in section 5.5.

Box 5.1 Examples of objectives for an ecosystem

This box includes examples of SMART objectives that could be applied to the ecosystem: snappy gum *Eucalyptus leucophloia* low open woodlands with a spinifex-dominated ground layer (Plate 1.1 a). The figures and percentages are fictitious. Some of the objectives can only be evaluated over several burns and years. Others apply to individual burns (burn-specific objectives) and can be assessed upon completion of a burn.

Background

Landscapes dominated by this ecosystem are highly fire-prone due to a combination of fuel type, fuel accumulation and dry season weather conditions. A widespread bushfire can be expected every few years in the absence of effective planned burns. These bushfires result in large areas of uniform-age vegetation.

Increasing the proportion and size of long unburnt patches is critically important to maintaining biodiversity in these landscapes. However, larger (and more) patches will typically be more fire-prone than smaller (and fewer) patches. There will need to be a trade-off between patch size (and number) and reduced bushfire risk.

Strategic management direction:

To improve the condition of the ecosystem to Good (as defined in the VBMF management plan) through proactive planned burning for ecological purposes and a reduction in late dry season bushfires.

Objectives:

Fire seasonality

Reduce the proportion of burns occurring, and the area burnt, in the late dry season.

SMART objectives:

- The percentage of area burnt each year is greater in the early dry season (EDS) because of planned burning, than in the late dry season (LDS).
- The number and size of burn patches in the LDS decreases over time and are less than in the EDS by 2025.
- By 2030, the annual average percentage of the area burnt over five years is 10–20% in the EDS and less than 5% in the LDS.

Size and distribution of unburnt patches

The size and connectivity of unburnt patches at the start of the bushfire season are such that the risk of widespread bushfire impacts is low.

SMART objective:

- No unburnt patches greater than 1,000ha by the start of the bushfire season.

Average burn patch size

The average burn path size is small enough to facilitate survival and recolonisation by fauna and flora species.

SMART objective:

- The annual average size of burn patches decreases over time, with an annual average size of less than 100ha by 2030.

Box 5.1 Examples of objectives for an ecosystem (continued)

Average distance to unburnt patches

The average distance to unburnt patches is small enough to facilitate survival and recolonisation by fauna and flora species.

SMART objective:

- The average distance from any burnt patch to the nearest unburnt patch is less than 600m.

Fire frequency

The percentage of the area burnt annually decreases through time.

SMART objective:

- By 2030, the percentage of the ecosystem burnt annually is less than 30%.

Retention of relatively long unburnt patches

The area of longer-unburnt vegetation increases over time.

SMART objective:

- By 2030, the percentage of the ecosystem unburnt for greater than two years is between 70–80%.

Box 5.2 Examples of burn-specific objectives

Strategic management direction:

Maintain the extent of the rainforest community on Mount Jake, and improve its condition, by excluding fire and protecting it from scorch along the margins.

SMART objectives:

- Fuel in adjacent fire-adapted ecosystems is reduced to less than x t/ha across x% of the burn area.
- Unburnt patches in adjacent fire-adapted ecosystems are no greater than xha in size.
- No scorch along the rainforest margins.

Additional information

FLAME (the QPWS fire and pest management system): https://flame.des.qld.gov.au/

5.4 Implementing a burn

QPWS provides training and other resources on how to undertake planned burns (including equipment, logistics, safety). *The QPWS Planned Burn Guidelines: how to assess if your burn is ready to go* is a key resource along with various other decision support tools to assist with condition assessments (see Additional information). The aim of this section is to highlight key considerations when implementing a planned burn for ecological purposes.

The timing, techniques and tactics used in a planned burn are determined by the objectives and characteristics of the environment.

Routine preparations include:

- consulting with First Nations partners
- communicating with neighbours and stakeholders about the intent to burn and the purpose of the burn
- assessing conditions (e.g. weather patterns, local weather conditions, soil and litter moisture/fuel hazard and curing) and conducting test burns to determine whether it is appropriate for the burn to proceed
- planning for containment and contingencies
- addressing biosecurity protocols.

Ensure all people involved in a burn are fully briefed on its purpose and why particular tactics will or will not be used.

Additional information

QPWS operational guides and protocols:

DERM 2012, *QPWS Planned Burn Guidelines: how to assess if your burn is ready to go* (internal)

QPWS Fire Operations Field Guide – personal training and experience log (internal)

Fuel Hazard Guide:

Hines et al. 2010, *Overall Fuel Hazard Assessment Guide*. (external)

Other resources:

Australian Fire Danger Rating System (external)

Sabre fire behaviour prediction tool (requires login; discuss with your Regional Fire Coordinator) (external)

Various sources of weather forecasts (e.g. BoM MetEye, BoM Fire weather services)

5.4.1 Mosaic burning

Mosaic burning is fundamental to fire management for ecological purposes. It also significantly reduces the risk of bushfire and improves the ability to manage bushfires, by limiting areas of single-aged vegetation (see Box 3.1 and Appendix 3).

Mosaic burning can be achieved on small scales through ground-based burning. However, aerial ignition is essential for mosaic burning at larger scales and in otherwise inaccessible areas (Plate 5.1). Aerial ignition also allows low-intensity burns adjacent to remote or inaccessible features that are not intended to be burnt (e.g. creek lines or rainforest patches) and to burn downhill from ridgelines (see case study 5.3).

Regardless of the ignition method (ground-based or aerial), it is important to have on-ground knowledge of the ecosystems and landscapes being managed with fire. The strategic use of weather, seasonal conditions and moisture gradients/differentials is essential. Preparedness to undertake staged or progressive burning (section 5.4.2), if necessary, is also required.

There is no formula for mosaic burning. The goal is to create a mosaic over time, and the best way to achieve this will vary depending on the ecosystems, topography, fuel types, moisture gradients and fire history.

Some general guidance on timing and ignition tactics is provided in sections 5.4.2 and 5.4.3. The approach needed in the early years of implementing mosaic burning (e.g. when the landscape is dominated by a single age-class), may differ from that required in later years as the mosaic develops. Case studies 5.1 and 5.2 demonstrate the use of multiple burns with aerial ignition to achieve mosaic burning objectives.

The development of spatial and temporal mosaics across the landscape can substantially reduce the need for, and reliance on, constructed fire lines and ground crew (see case study 5.1). While strategic fire lines are important, they increase the risk of invasion by pest species, fragment the habitat of some native species and may impact water quality. Fire lines also require ongoing resources for maintenance.

A benefit of aerial burning is that it enables access to otherwise inaccessible areas.

A potential risk of aerial burning is that it enables access to otherwise inaccessible areas.

Old growth refugia and ecosystems requiring long fire intervals (e.g. montane heath) must not be targeted unless doing so aligns with long-term objectives in the fire strategy and it has been agreed by the Fire Referral Group.

Plate 5.1 Aerial ignition allows access to remote endangered tussock grasslands to restore and maintain them, Kutini-Payamu (Iron Range) National Park (CYPAL). *Photo: Andy Baker © Qld Govt.*

5.4.2 Timing

When to burn (season, time of day, prevailing weather conditions) is determined by the objectives of the burn, the conditions required to achieve them and the characteristics of the burn area.

Remember that the response of ecosystems and species, and hence the outcomes of a planned burn, do not just depend on the conditions leading up to and during a fire. They also depend on the conditions in the weeks and months after the fire. It is also important to consider the typical and forecast seasonal outlooks for the period following the burn to minimise the risk of reignition.

For landscape-scale burning, particularly when first applied, it is usually best to begin at the end of the wet season or in the early dry season when soils and fuels are moist and to implement burns over several days, weeks or months. This practice, known as staged or progressive burning, will help achieve the patchiness and connectivity of burnt and unburnt areas required.

Advantages of staged burning include:

- helping to build understanding and confidence in burning the local ecosystems and landscapes
- enabling areas with different characteristics (e.g. moisture regimes) to be burnt when they are 'ready'

- providing the opportunity to safely undertake more challenging burns very early when moisture is high
- providing increased opportunity to undertake more challenging burns in the dry season because there are adequate fuel-reduced patches across the burn area to minimise the risk of bushfire
- providing a much larger window of opportunity for burning particularly under a changing climate.

Staged burning may also extend the period over which food sources are available to fauna in some ecosystems (e.g. seed for granivores, see case study 3.4).

QPWS has a bushfire risk period defined at a regional and state level. This is when there is potential for negative impacts from bushfires, including impacts on life and property. However, across such a large and diverse state, there are likely to be good opportunities to burn in some locations (particularly in wetter environments) during this period. Staged burning facilitates these opportunities.

Plate 5.2 Early dry season aerial ignition in northern bettong *Bettongia tropica* habitat, Davies Creek and Dinden National Parks. *Photo: Andy Baker © Qld Govt.*

Storm-burning (i.e. lighting fires after the first wet season rains and when follow-up rain can be reliably expected) can be beneficial. This is because it is at the start of the growing season for many herbaceous species, including many native grasses, rather than at the peak of flowering and fruiting. These burns are likely to create favourable conditions for good regeneration and seed production. Incorporating regular storm-burning in the fire regime may also be an effective tool for preventing and reversing the thickening of grasslands and grassy woodlands by native trees and shrubs such as *Melaleuca* spp. (see case study 3.4).

Be flexible and ready to take windows of opportunity when they arise. This is increasingly important with climate change.

Increase your windows of opportunity by adopting staged burning.

Additional information

Crowley et al. 2009, 'Impact of storm-burning on *Melaleuca viridiflora* invasion of grasslands and grassy woodlands on Cape York Peninsula, Australia', *Austral Ecology*, vol. 34, 196–209.

Plate 5.3 Aerial storm-burning, Rinyirru (Lakefield) National Park (CYPAL). *Photo: Andy Baker © Qld Govt.*

5.4.3 Ignition and lighting patterns

Spot ignition

Spot or point ignition is typically used in ecological burns rather than line ignition because it enables better control over the rate of spread and intensity of the fire. The distance between ignition points can be readily adjusted to suit conditions and achieve the objectives of the burn.

Spot ignition can be used in a range of lighting patterns. It can result in fire movement in all directions (head, backing and flanking). Spot ignition across the landscape, and to a lesser degree, from a fire line or natural edge, typically provides for the greatest diversity in fire intensity within an individual burn.

Spot ignition in a series of parallel lines produces a grid pattern of ignitions (grid ignition). This can be an effective way to achieve patchy, low-intensity burns in the late wet to early dry season because if a fire runs into an adjoining one, it does so before reaching its maximum potential intensity. The network of burnt patches helps reduce the risk of extensive bushfire later in the dry season. Different lines can be flown in subsequent years to increase variation in fire intervals within the grid.

Grid ignition in the late wet to early dry season, using an annual rotating grid, has been successful in highly fire-prone landscapes. The practice is known as systematic ignition.

When consistently applied, grid ignition techniques prevent the development of large contiguous areas of even-aged fuel. This helps minimise the extent and rate of spread of bushfires. This, in turn, reduces the risk to fire-sensitive values and helps retain more longer unburnt vegetation within the burn area. Various forms of grid ignition are used successfully on park (see case studies 5.1 and 5.2).

Line ignition

Line ignition is useful where a more uniform and intense burn is required. It is rarely appropriate for ecological purposes, but exceptions may include burns to reverse rainforest establishment within eucalypt communities and burns for weed control.

Avoid encircling an area with fire. It increases intensity and therefore scorch height and reduces patchiness. It also limits the opportunity for fauna to escape the fire.

Orientation of ignition lines

The orientation of ignition lines to wind direction and/or slope can be used to influence the outcomes, with different proportions of the target area being burnt by backing-fire, flanking fire and head fire.

Use wind direction to assist or limit fire spread and intensity, depending on what is required. A backing-fire (burning back against the wind or downslope) can be used to slow the progress of fire across a burn area. A head fire (with the wind) can be used to promote fire spread and intensity where this is desirable (e.g. to carry fire through heathland). Backing and flanking fires are much lower intensity than head fires and typically result in greater patchiness.

Burning downslope, rather than upslope, ensures a slower rate of spread and lower intensity burn. The rate of spread doubles with every 10° increase in slope because the fuel is preheated. There may be some circumstances where burning upslope is desirable to achieve burn objectives (e.g. reverse rainforest establishment in sclerophyll communities). It will be impossible in some landscape-scale burns to always burn downslope, but timing can help minimise the risk and impact of fire that burns upslope (e.g. by burning in the late wet to early dry season with moisture or late in the day).

Avoid routinely burning from roads and tracks as it promotes weed invasion and establishment.

If it is necessary to burn from roads and tracks, then rake around hollow-bearing trees and large fallen logs. This will minimise the loss of critical habitat and likely save time, and reduce risk, in the long run.

Case study 5.1: Boodjamulla National Park (Gulf Plains Bioregion)

The planned burn program at Boodjamulla has established a complex mosaic of burn ages across the park, successfully breaking a cycle of periodic widespread bushfires and providing more long unburnt refugia.

The landscape at Boodjamulla is dominated by highly flammable woodlands with a spinifex *Triodia* spp. understorey. Vegetation grows rapidly during the hot, wet summers but dries out quickly during the dry season. Late dry season ignitions, either from humans or lightning strikes, cause bushfires that are mostly impossible to contain in the absence of recently burnt areas. In the past, planned burns were insufficient to prevent broadscale bushfires every five or so years. With each bushfire event, substantial areas of the park returned to young, post-fire age-classes.

In 2012, a proactive burn program was established. The objectives are to: reduce the risk of widespread bushfire, increase the heterogeneity of burn ages across the park, and increase the number and size of long unburnt patches.

The burn program involves burning each year in the early dry season using aerial point ignition along a series of parallel lines, forming grids of ignition points. The program also includes additional ignitions at strategic locations. The flight path shifts each year depending on outcomes from the previous years (Figure 5.1 and Plate 5.4). Staged (progressive) burning over weeks or months is used to create an adequate network of burnt patches.

Ten years into the program, sufficient fine-scaled heterogeneity of fuel ages has been created to allow the aerial program to become more targeted. Fire history, topography and the location of fire-sensitive vegetation or longer unburnt refuges are now used to pinpoint areas to burn. There is minimal need for constructed fire lines and ground crew to implement these burns. While the treated area remains large, relatively small areas are burnt in any given year to achieve the ongoing objectives of the burn program.

Additional information

Burrows et al. 2021, 'Fire mosaics in south-west Australian forest landscapes', *International Journal of Wildland Fire*, vol. 30, 933–945.

Ezzy 2022, 'Breaking the wildfire cycle: progressive fire management can shift fire regimes and improve ecosystem condition – a case study from a large conservation reserve in northern Australia', *Rangelands Journal*.

Melzer et al. 2019, 'Health Checks: a simple tool for assessing the condition of values and effectiveness of reserve management', *PARKS*, vol. 25, 67–78.

Radford et al. 2020, 'Prescribed burning benefits threatened mammals in northern Australia', *Biodiversity and Conservation*, vol. 29, 2985–3007.

Case study 5.1: Boodjamulla National Park (Gulf Plains Bioregion) (continued)

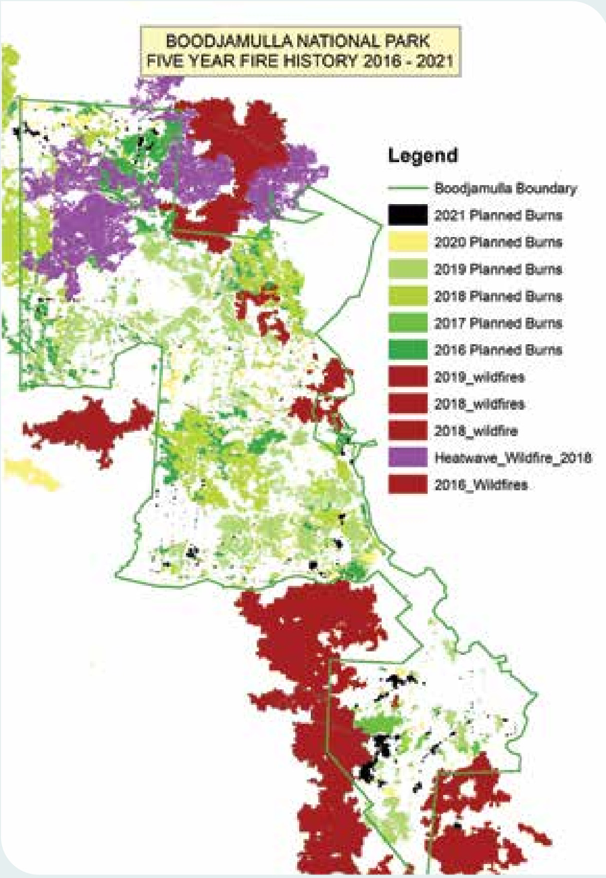

Figure 5.1 (left) Planned burn scars created from 2016 to 2021 with each year shown in different shades of green and yellow and 2021 shown in black. Bushfires (shown in red and purple) in the late dry season pulled up on the planned burn scars.

Plate 5.4 Aerial burning in the early dry season to create patchy burns at a landscape scale, Boodjamulla.

a. (below left) implementing the burn.

b. (below right) resultant multi-age stand of spinifex evident from recently burnt hummocks, ranging through small, disconnected hummocks to large, contiguous hummocks on upper slopes.

Photos: Lea Ezzy © Qld Govt.

Case study 5.2: Curtis Island National Park (Southeast Queensland Bioregion)

Staged (progressive) burning is being used at Curtis Island National Park to establish a range of post-fire age-classes in an extensive area of even-aged, long unburnt, fire-adapted ecosystems.

Grassy to shrubby coastal eucalypt woodland to open forests dominate much of Curtis Island National Park. In early 2020, most of this community was even-aged and long unburnt (>25 years). This increased the risk of widespread bushfire damaging ecosystems and species, and external assets, such as the liquid natural gas plant.

The objectives in the park's fire strategy include creating a mosaic of burn ages across these ecosystems with at least 20% of their area being within the recommended fire interval by 2023, and 40% by 2030. To achieve this, low-intensity, patchy burns will be implemented in most years. This will create a range of age-classes including long unburnt habitat.

The burn program commenced in 2020. With an extensive area of long unburnt vegetation, the initial approach was to begin lighting before the vegetation would normally be considered ready to burn and when fires would almost certainly extinguish overnight.

Burns were implemented using aerial spot ignition along a series of parallel lines, with the first runs conducted during the wet season (February) under very mild conditions (high soil moisture, low Keetch-Byram Drought Index, high humidity, low wind).

The area was progressively burnt, with further aerial ignition runs in March and May (Figure 5.2). The last burn took advantage of a late-season rain event (Plate 5.5), as conditions in May on Curtis Island are usually too dry to achieve low-intensity, patchy burns.

The three burns were conducted over a treatment area of about 10,000ha with approximately 3,500ha of the area burnt, creating a network of burnt and unburnt patches. Staged burning will continue to be implemented over the coming years to achieve the objectives of the fire strategy.

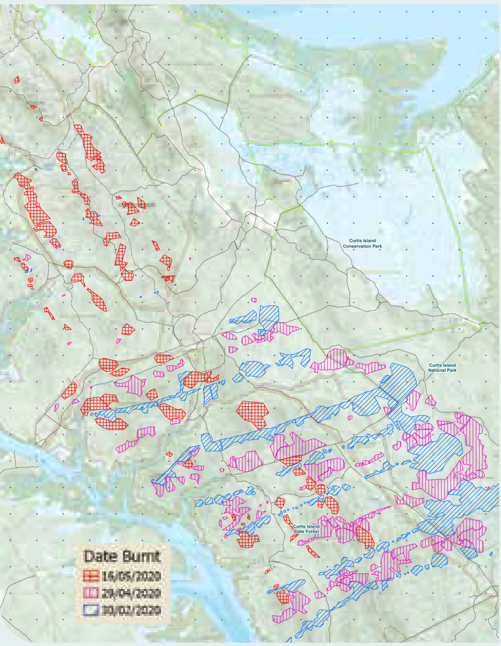

Plate 5.5 (above) Successful ignition of the final progressive burn, in vegetation not burnt for over 25 years, in May 2020 five days after 200mm of rain.

Photo: Jack Hargreaves © Qld Govt.

Figure 5.2 (left) Patches burnt on Curtis Island National Park using progressive aerial ignition in the wet and early dry seasons of 2020. Each of the three progressive burns is shown in a different colour.

Case study 5.3: Marengo and Moolayember Sections, Carnarvon National Park (Brigalow Belt Bioregion)

Fire-sensitive brigalow and semi-evergreen vine thicket/forest (SEVT) communities in Carnarvon National Park have suffered significant impacts from bushfires fuelled by buffel grass *Cenchrus ciliaris*. Reducing fuel loads in fire-adapted ecosystems adjacent to brigalow and SEVT is a priority to minimise further losses from bushfire.

In February 2021, planned burns using ground-based and aerial ignition were undertaken during a week following 50mm of rain when, although the temperature was around 30°C, there was a low Keetch-Byram Drought Index. The rain provided a narrow window of opportunity, as conditions would otherwise have been too dry to safely achieve the desired outcome.

A helicopter was used to enable a high level of precision in the ignitions. Incendiaries were dropped along ridges to promote low-intensity burns running downslope to the SEVT situated below (Plate 5.6). Ground crews used spot ignition adjacent to brigalow communities in the lowlands later in the day (when conditions were milder) and burnt away from the community towards control lines (see Plate 5.7). While that was a slow process it helped reduce fire intensity and ensured minimal scorch to the margins of the fire-sensitive community. This was despite fuel loads of 16–20t/ha, dominated by buffel grass.

Planned low-intensity fire needs to be undertaken regularly in this landscape to minimise the risk of bushfire impacts or adverse planned burn outcomes.

Plate 5.6 Aerial ignition along ridges to promote low intensity burns running downslope. The high soil moisture and calm conditions further reduced the risk of fire burning into adjacent fire-sensitive ecosystems.
Photo: Lindie Pasma © Qld Govt.

Plate 5.7 The outcome of ground-based ignition in an area dominated by dense buffel grass *Cenchrus ciliaris* and impacted by previous bushfires; adjacent to intact fire-sensitive brigalow and SEVT in the background.
Photo: Lindie Pasma © Qld Govt.

5.5 Assessment, monitoring and evaluation

The successes and failures of each burn and the overall burn program should inform and improve future fire management for ecological purposes. This is an essential component of adaptive fire management.

Each burn should be assessed and evaluated against the objectives. An inspection of the burn area and debrief of the outcomes is a valuable part of this assessment.

The outcomes of each burn are recorded in FLAME. This includes thoroughly documenting the weather conditions leading up to and after the burn, mapping (section 5.5.1) and recording whether burn-specific objectives were met.

The objectives (section 5.3.1) determine the type of assessment or monitoring required for the evaluation. Examples of how to assess burn-specific objectives are provided in each of the bioregional guidelines.

The monitoring requirements associated with objectives that are not burn-specific are captured in the monitoring and research strategy (section 1.2.1). A project plan should be developed if detailed monitoring is required. The project plan should clearly identify the desired outcomes and strategic management directions and address objectives, methods, timeframes, resourcing, data management and data capture.

Monitoring should be 'fit for purpose' but as simple as possible. Photo monitoring is a simple tool that can be invaluable. Photos provide a visual record of vegetation structure, composition and fuel loads. When taken from the same location, comparisons can be made over time.

Another simple tool is Health Checks. This is a qualitative approach to evaluating and reporting on the condition of most key values. Some of the Health Check indicators and their associated criteria are useful for developing SMART objectives (Table 5.1) and for evaluating outcomes. An example of how a Health Check can be used for monitoring is provided in Table 5.2.

In some cases, more detailed monitoring will be required. BioCondition (a vegetation condition monitoring framework) is an example of a detailed monitoring tool. It assesses attributes (e.g. large trees, shrub cover, coarse woody debris, native perennial grass cover, recruitment of canopy species) that are indicators of functions (e.g. provision of reliable food, shelter and/or breeding sites for wildlife) that contribute to maintaining vegetation and flora and fauna biodiversity.

Research needs relating to a fire strategy are identified in the monitoring and research strategy and captured in the QPWS Research Prospectus database. Partnering with researchers has enhanced fire management delivery, including through the development of detailed guidelines (see case studies 3.4 and 3.5).

Table 5.2 Example of how criteria for a Health Check indicator are used to assess the effectiveness of a planned burn program. Using the objective from Table 5.1 (for the SMD – maintain extent and condition of semi-evergreen vine thicket): *Ecosystem-changing pest plants are absent (G) or 'inconspicuous' (GC) at all sites and no worse than GC for the General Impression*, the Health Check criteria below can be used to measure success.

Level of invasion	Description	Condition Class
None	Pest species are absent including on the margins.	Good
Inconspicuous	Native species dominate; pest species inconspicuous or mainly on margins. • Pest species in ground stratum – comprise up to 5% of cover and/or • Pest shrubs/trees – comprise up to 5% of stems or cover and/or • Pest climbers – cover up to 5% of canopy.	Good with Some Concern
Conspicuous	Pest species are a conspicuous component of the vegetation. • Pest species in ground stratum – comprise 5-25% of cover and/or • Pest shrubs/trees – comprise 5-25% of and/or • Pest climbers – cover 5-25% of canopy.	Significant Concern
Dominant	Pest species dominate • Pest species in ground stratum – comprise ›25% of the cover and/or • Shrubs/trees – comprise ›25% of stems or cover and/or • Pest climbers – cover ›25% of canopy.	Critical

QPWS can contribute valuable information, and opportunities for researchers, to build an understanding of how species respond to fire (e.g. mortality, recolonisation, reproduction) and how the factors that influence them (e.g. food and nutrient availability, availability of nesting/shelter habitat, predation pressure) vary with different fires, fire regimes, landscapes and climate.

Observations on plant species' responses are easily collected and can be highly informative when coupled with details on burn conditions, fire history and location.

Additional information

Eyre et al. 2015, BioCondition: a condition assessment framework for terrestrial biodiversity in Queensland, *Assessment Manual*, version 2.2.

Falster et al. 2021, 'AusTraits, a curated plant trait database for the Australian flora'. *Scientific Data*, vol 8, article 254.

Melzer et al. 2019, 'Health Checks: a simple tool for assessing the condition of values and effectiveness of reserve management', *PARKS*, vol. 25, 67–78.

Melzer 2019, Natural Values Health Checks. A guide to undertaking Health Checks for key natural values (internal)

Melzer 2022, Using Health Checks as a monitoring tool for pest and fire programs – a guide (internal)

5.5.1 Spatial data and fire mapping

Burn maps can be developed within or imported into FLAME.

Maps should show burnt and unburnt patches within the burn extent at a resolution and scale that provide the precision required for the intended purpose. Care should be taken to document the resolution of the data to avoid reporting false precision.

Mapping burn boundaries on the ground with a handheld GPS device can provide resolution from 2 to 30m depending on terrain, canopy density, atmospheric conditions and satellite availability. Mapping from a fixed-wing aircraft or helicopter is likely to provide a resolution of >50m. Mapping using GIS and high-resolution imagery such as Sentinel-2 can provide a resolution of 10m or less. MODIS has a poorer spatial resolution (between 250m and 5600m pixels, depending on the band/s used) but offers a wide spectral range and relatively high temporal resolution. MODIS visits the same location every one to two days.

Fire severity mapping, developed from pre- and post-fire satellite imagery, may sometimes be required to assess the ecological outcomes of bushfires. For example, where a natural key value or other significant natural value is:

- identified in a fire strategy as having specialised fire regime requirements
- subject to a research or monitoring program, and/or
- likely to have been adversely affected by a fire.

Online tools, such as the Northern Australia and Rangelands Fire Information (NAFI) fire scar and fire history mapping and Savanna Monitoring and Evaluation Metrics (SMERF), can help with burn mapping and evaluating improvements in surrogate measures for biodiversity conservation. Surrogate measures may include the number and size of burns in early versus late dry season, fire frequency and interval, patch size and distance to unburnt patches (Figure 5.3). These tools are currently available for northern Queensland and parts of west, southwest and central Queensland.

Additional information

DEHP 2017b, *Field guide for managing fire in northern bettong habitat*.

Northern Australia and Rangelands Fire Information (NAFI) fire scar and fire history mapping https://firenorth.org.au/nafi3/

Savanna Monitoring and Evaluation Metrics (SMERF) https://www.smerf.net.au/

Fire severity mapping and assessing ecological outcomes:

Campbell-Jones et al. 2022, 'Fire severity has lasting effects on the distribution of arboreal mammals in a resprouting forest', *Austral Ecology*, 13231.

Hines et al. 2020, 'The extent and severity of the Mackay highlands 2018 wildfires and the potential impact on natural values, particularly in the mesic forests of the Eungella-Crediton area', *Proceedings of the Royal Society of Queensland*, vol. 125, 139–157.

Laidlaw et al. 2022, 'Beyond bushfire severity: mapping the ecological impact of bushfires on the Gondwana Rainforests of Australia World Heritage Area', *Australian Zoologist*, vol. 42, 502–513.

QPWS post-fire assessment reports including fire extent and severity mapping: https://parks.des.qld.gov.au/management/programs/fire-management/post-bushfire-evaluation/_nocache

QPWS (draft) 2020, *Procedural Guide – Guide to determining the need for post-bushfire evaluation of impacts on key and other significant natural values to inform future management* (internal)

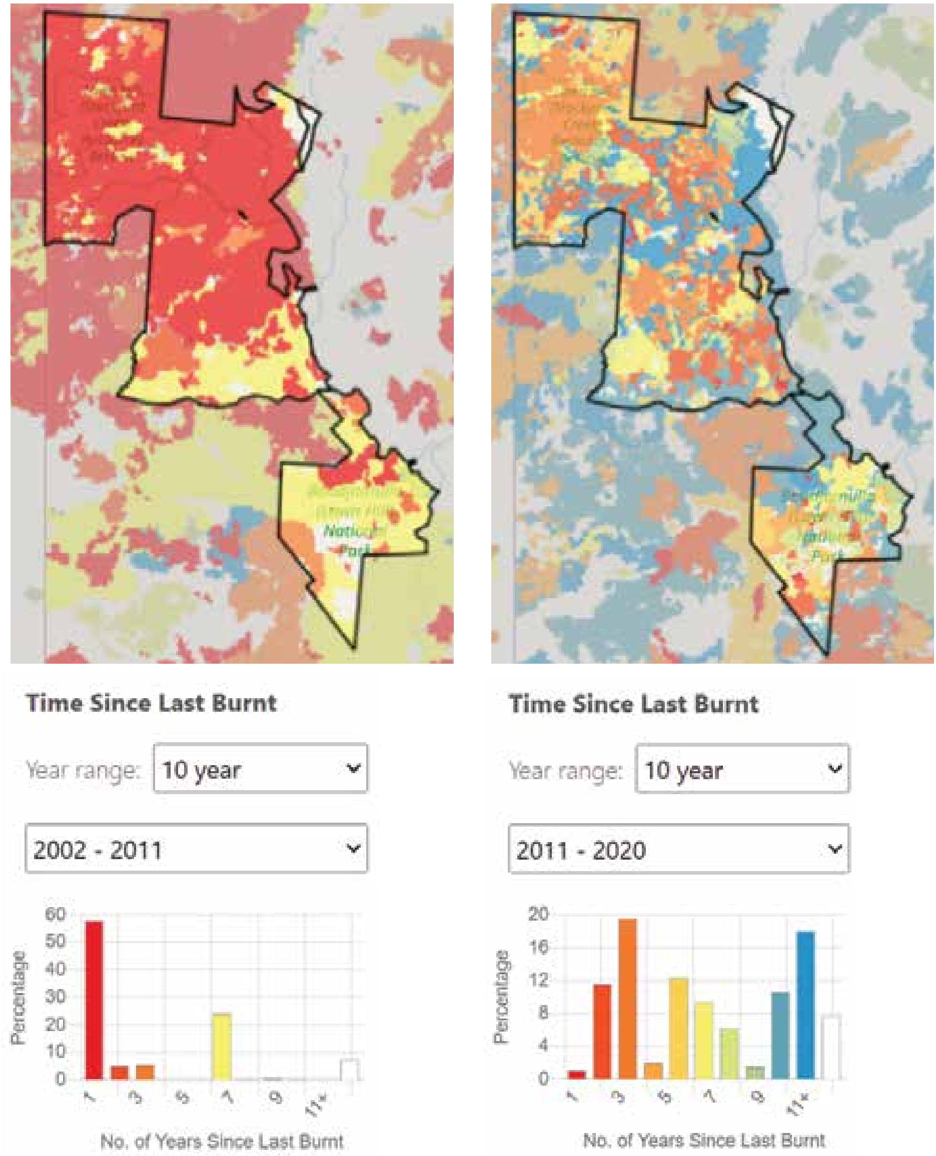

Figure 5.3 Example of spatial data available from SMERF (NAFI) for Boodjamulla National Park. The number of years since the last burn is shown for the 10-year periods from 2002–2011 and 2011–2020, demonstrating the success of the planned burn program in re-establishing a diverse mix of fire age classes (see case study 5.1).

6 Major disturbance events: refining fire management

6.1 Bushfire

A planned burn program may require adjustment after a bushfire.

Not all bushfires are created equal. Some bushfires have similar outcomes to planned burns and can replace a planned burn, where the objectives of that planned burn were met. Others have detrimental impacts, and a review of the burn program, and likely also the fire strategy, will be required.

After a bushfire, it is important to understand the impacts on ecological values. It is also important to consider threats to these ecological values, including the increased risk of negative consequences from future bushfires and threats that may impede ecological recovery (e.g. erosion, weed invasion, grazing, predation).

Do not waste the opportunity to learn from bushfires.

Evaluate their impact (positive or negative) on progress towards meeting fire strategy objectives and the strategic management directions.

Consider how the bushfire has impacted the ability to achieve desired outcomes for ecosystems and species, particularly key values.

- Are the desired outcomes still attainable? It will be rare that they are not but the timeframes for achieving them may be longer.
- What actions are required to address bushfire impacts and facilitate recovery? For example, integrated recovery actions may be needed, such as a combination of fire and weed management.

A formal post-bushfire evaluation may be required if the park or forest has a High to Exceptional Level of Service for natural values and the fire is likely to have significantly impacted a natural key value or other significant natural value (e.g. World Heritage Area, wetland of international significance, fire-sensitive ecosystems, peat-based ecosystems). A draft procedural guide is available for determining the need for a formal post-bushfire evaluation (QPWS 2020). Examples of completed evaluations are provided in Additional information.

Do not fall into the trap of short-term thinking.

Consider recovery in the context of the timespan of cycles in the ecosystems in question.

After a bushfire, many factors will determine the planned burning required. These include the extent of the bushfire, the ecosystems involved and their recovery mechanisms. Some common scenarios are outlined below with suggested approaches to planned burning. A simple decision diagram is shown in Figure 6.1 to help guide actions after a significant bushfire event.

Widespread, even-aged vegetation and fuel

Widespread, damaging bushfire typically converts large areas of the landscape to an even-aged young state. The aim is to progressively re-establish a mosaic.

It is often necessary to recommence burning earlier than the recommended fire interval for the ecosystem, to begin the process of breaking up uniform fuel loads. What constitutes an appropriate 'return interval' will depend on how long an ecosystem requires to regenerate after fire.

Take care to retain older age-classes, including priority long unburnt and old-growth patches.

Widespread, dense, woody regrowth

Bushfires, particularly in dry conditions, can result in dense woody regrowth in some ecosystems due to mass seed germination or suckering. Widespread woody regrowth can impede recovery and increase the likelihood of maintaining a cycle of high-intensity fire.

The appropriate remedial action will depend on the woody species involved, its reproductive response in relation to fire and the ecology of the impacted ecosystem. The advantages and disadvantages of different remedial options should carefully be considered. For example, in grassy ecosystems, it may be possible to safely conduct a planned burn to kill some of the regrowth before flowering and seed set. However, there may be a substantial seed bank or suckering capacity remaining after the initial bushfire. Successive planned burns may be needed to run down the seed bank and/or suckering capacity of the target species. The impacts of successive fires on non-target species and the overall ecosystem should be considered when determining the appropriate action.

Some ecosystems are naturally shrubby rather than grassy due to geology and soil type. If bushfire in these ecosystems results in dense woody regrowth, safely introducing early planned burns to reduce regrowth density is unlikely to be possible. Competition will help resolve the issue over time (typically long timeframes) if bushfire can be excluded.

Burnt fire-sensitive ecosystems or ecosystems requiring long fire intervals

Fire exclusion will be required where bushfire impacts fire-sensitive ecosystems or fire-adapted ecosystems that require long fire intervals. Ensure the necessary changes to strategic management directions are documented in the fire strategy. Modify the burn program as required.

Burning adjacent fire-adapted ecosystems under appropriate conditions (see case study 5.3) and managing other threats (e.g. ecosystem-changing weeds) is likely to be important to ensure fire is excluded.

Drought stress

Damaging bushfires often occur under drought (strong moisture deficit) conditions. Vegetation communities and the plant and animal species that live within them are likely to be under stress before the fire. Fire worsens this stress. Avoid or substantially limit planned burning within and adjacent to the burnt area until conditions have markedly improved, the ecosystem is in recovery, and the soil and woody fuels are moist.

Ongoing evaluation of the impacted ecosystems and landscapes, and the effectiveness of interventions, is important to enable informed adjustments to management.

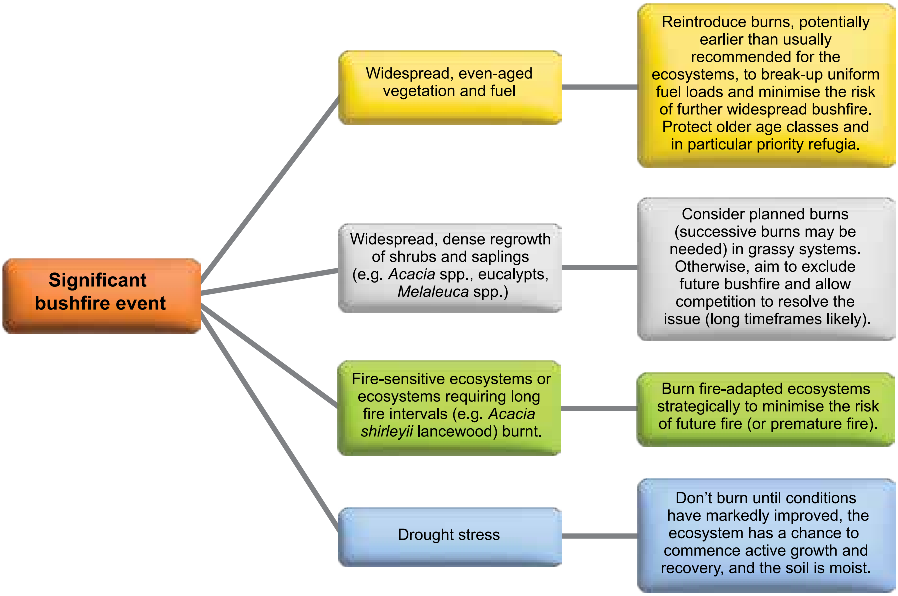

Figure 6.1 Decision tree to guide actions after a significant bushfire event.

Additional information

Fire in disturbed rainforest:

Hines et al. 2020, 'The extent and severity of the Mackay highlands 2018 wildfires and the potential impact on natural values, particularly in the mesic forests of the Eungella–Crediton area', *Proceedings of the Royal Society of Queensland*, vol. 125, 139–157.

House et al. 1998, 'Crediton burning: rainforest recovery after fire in the Clarke Range, Queensland', in *Working Papers – Seventh Queensland Fire Research Workshop*, Cairns.

QPWS (draft) 2020, *Procedural Guide – Guide to determining the need for post-bushfire evaluation of impacts on key and other significant natural values to inform future management.* (internal)

Examples of QPWS post-fire assessment reports, including fire extent and severity mapping. (external)

6.2 Severe storms and cyclones

Severe storms and cyclones often result in sudden and substantial accumulation of surface and suspended fuels. There may be increased continuity of fuel across large areas. Timber harvesting can have similar effects but now occurs on a small scale.

The disturbance caused by storms and cyclones, including opening up the canopy, provides an opportunity for weed invasion and/or an increase in native ground and shrub cover.

These weather events are becoming more severe with climate change.

Once dry, the changed fuel conditions can:

- increase the fire intensity
- alter fire behaviour for several years after the event
- promote high-intensity fire in ecosystems where that is undesirable (e.g. riparian communities)
- increase the vulnerability of fire-sensitive ecosystems to fire incursion.

On the other hand, changed conditions may provide an opportunity to reintroduce fire to sclerophyll ecosystems transitioning to rainforest. Eucalypts need abundant light and bare soil to germinate and establish. Planned burning after storms and cyclones may enable eucalypts to establish and slow or even halt the transition.

A strategy for reducing fuel in priority areas should be developed and implemented soon after the event. This includes reviewing the current schedule of planned burns. There must be careful consideration of the burn conditions required to achieve desired outcomes in the changed conditions. Scheduled planned burns may need to be rescheduled to be conducted under moister conditions than usual to compensate for the changed fuel conditions.

Cyclone- and storm-affected trees are vulnerable to additional stressors, such as high-intensity fire and canopy scorch, so it will usually be important to implement planned burns in priority areas before the following dry season to minimise the risk of bushfire. Burning under conditions that ensure a low-intensity fire is important. If the risk of ignition is low, it may be appropriate to exclude fire until an ecosystem recovers to a point that the additional stress from a planned burn is unlikely to be detrimental.

Appropriate tactics and timing are needed to protect fire-sensitive ecosystems, even if they are normally self-protecting. Damaged canopies and invasion by ecosystem-changing weeds, such as lantana *Lantana camara* and high-biomass grasses, will significantly increase the risk of fire incursion.

Generally, the best time to start burning is soon after good rain. The moist, humid conditions help promote lower intensity, patchy, slow-moving fires that minimise further stress on the ecosystem. This also gives disorientated and distressed fauna more opportunity to find refuge while creating sufficient residence time to reduce the fuel loads.

If it is impossible to burn under ideal conditions, the time of ignition (e.g. afternoon and evening) and ignition tactics, such as burning downslope and/or against the wind, become even more important.

After a severe event, there will be many logs and large branches on the ground for years afterwards. If these are dry before a planned burn, they may smoulder for weeks to months and create a reignition risk, especially late in the dry season. Burning early when coarse woody debris is wet greatly reduces this risk.

Plate 6.1 Coastal eucalypt open forest, five years after Cyclone Marcia, Shoalwater Bay Military Training Area.
Photo: Andrew McDougall © Qld Govt.

6.3 Floods

Riparian and floodplain ecosystems are most impacted by major flood events. Ground and mid-stratum vegetation may be completely removed, and trees and shrubs uprooted. Soil is often eroded from upstream and deposited downstream. Post-flood conditions are likely to encourage weed invasion and establishment, and some weed species may impede regeneration and increase fire risk.

While floods may have negative impacts on ecosystems they also bring significant ecological benefits. For example, the piles of debris that may increase fuel hazard also provide valuable fauna habitat. The silt deposited by floods is critical to the regeneration of some plant species including coolabah *Eucalyptus coolabah*.

A review of the burn program, and possibly also the fire and pest strategies, may be required to address both the negative and positive outcomes of a major flood. Integrated weed and fire management may be required.

It will rarely, if ever, be appropriate to burn in-stream vegetation and debris. Whether burning, to reduce post-flood fuel loads, is appropriate in the vegetation fringing a waterway with depend on the ecosystem/s. However, unless debris poses a significant risk to adjacent values (e.g. fire-sensitive ecosystems), it may be appropriate to exclude fire where the risk of unplanned ignition is low.

Post-flood burn programs should aim to minimise destruction of new generations of native species that germinate and establish as a consequence of the flood. This is particularly important for long-lived woody species that depend on the conditions created by floods for successful recruitment.

Where it is appropriate and necessary to implement post-flood burning it will be critical to consider the influence of changed fuel loads and fuel structure on fire behaviour. The timing and tactics chosen should be appropriate to achieving biodiversity objectives. Burning should be conducted under moist conditions to help minimise impacts on ecosystems, especially riparian ecosystems, and fauna habitat.

6.4 Severe drought

Severe drought can profoundly affect the structure, composition and function of ecosystems. Some effects may be evident many years later, such as increased standing dead trees and large woody debris.

Drought puts substantial stress on ecosystems and species. Planned burns should usually be postponed until drought stress is alleviated.

Canopy cover is often reduced during drought, facilitating a surge in understorey growth following rain. In some circumstances, the understorey growth will be dominated by grasses. In others, the bare ground and increased light reaching the understorey provides ideal conditions for mass germination of woody species, such as eucalypts. Invasion by herbaceous and/or woody weeds may also be facilitated by drought.

The nature of regeneration and the rate at which it occurs after drought will depend on a range of factors, including the productivity of the area, the influence of grazers and browsers and fire regimes.

The desired outcomes for ecosystems and species impacted by drought may need to be reconsidered and so also the fire management required. Long-term perspectives are important. For example, if dense woody regrowth occurs, it will not always be possible or appropriate to intervene with fire. A long successional process, which includes self-thinning, may be best left to run its course. If ecosystem-changing weeds are present, weed control should be implemented early.

In most circumstances, fire management will continue to be integral to managing fire-adapted ecosystems after drought. Changed fuel types, fuel loads and fuel hazard may mean timing and tactics for burns need to change to ensure biodiversity objectives are achieved. Particular attention should be given to minimising the loss of dead trees and large woody debris, as these will provide important habitat in the future.

Plate 6.2 Drought death in narrow-leaved ironbark *Eucalyptus crebra* woodland, Durikai State Forest, January 2020. *Photo: Harry Hines © Qld Govt.*

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7 Bibliography

Andersen, AN 2021, 'Faunal responses to fire in Australian tropical savannas: insights from field experiments and their lessons for conservation management', *Diversity and Distributions*, vol. 27, 828–843.

Baker, AG, Catterall, C and Wiseman, M 2022, 'Rainforest persistence and recruitment after Australia's 2019–2020 fires in subtropical, temperate, dry and littoral rainforests', *Australian Journal of Botany*, vol. 70, 189–203.

Baker, J, Whelan, RJ, Evans, L, Moore, S and Norton, M 2010, 'Managing the ground parrot in its fiery habitat in south-eastern Australia', *Emu-Austral Ornithology*, vol. 110, 279–284.

Bateman, BL and Johnson, CN 2011, 'The influences of climate, habitat and fire on the distribution of cockatoo grass (*Alloteropsis semialata*) (Poaceae) in the Wet Tropics of northern Australia', *Australian Journal of Botany*, vol. 59, 315–323.

Bradstock, RA 2010, 'A biogeographic model of fire regimes in Australia: current and future implications', *Global Ecology and Biogeography*, vol. 19, 145–158.

Bradstock, RA, Gill, MA and Williams, RJ eds. 2012, *Flammable Australia: fire regimes, biodiversity and ecosystems in a changing world*, CSIRO Publishing, Collingwood, Victoria.

Bradstock, RA, Williams, JE and Gill, AM eds. 2002, *Flammable Australia. The fire regimes and biodiversity of a continent*, Cambridge University Press.

Bradstock, RA, Williams, RJ and Gill, AM 2012, 'Future fire regimes of Australian ecosystems: new perspectives on enduring questions of management', in Bradstock et al. eds. 2012, *Flammable Australia: fire regimes, biodiversity and ecosystems in a changing world*, 307–324, CSIRO Publishing, Collingwood, Victoria.

Burrows, N, Stephens, C, Wills, A and Densmore, V 2021, 'Fire mosaics in south-west Australian forest landscapes', *International Journal of Wildland Fire*, vol. 30, 933–945.

Campbell-Jones, MM, Bassett, M, Bennett, AF, Chia, EK, Leonard, S and Collins, L 2022 early online, 'Fire severity has lasting effects on the distribution of arboreal mammals in a resprouting forest', *Austral Ecology*, vol. 47, 1456–1469.

Clarke, M 2008, 'Catering for the needs of fauna in fire management: science or wishful thinking', *Wildlife Research*, vol. 35, 385–394.

Clarke, H, Tran, B, Boer, MM, Price, O, Kenny, B and Bradstock, R 2019, 'Climate change effects on the frequency, seasonality and interannual variability of suitable prescribed burning weather conditions in south-eastern Australia', *Agricultural and Forest Meteorology*, vol. 271, 148–157.

Clarkson, JR 2020, *Management of invasive and high biomass grasses on Queensland Parks and Wildlife Service managed lands*, Department of Environment and Science, Queensland Government.

Climate Change in Australia 2022, Queensland's changing climate. https://www.climatechangeinaustralia.gov.au/en/changing-climate/state-climate-statements/queensland/

Commonwealth of Australia 2018a, *Threat abatement plan for disease in natural ecosystems caused by Phytophthora cinnamomi*

Commonwealth of Australia 2018b, *Background document: threat abatement plan for disease in natural ecosystems caused by Phytophthora cinnamomi*

Commonwealth of Australia 2019, *Changes to fire weather in Queensland. A report from the Australian Bureau of Meteorology*, prepared for Queensland Fire and Emergency Services.

Commonwealth of Australia 2020, *State of the climate 2020. A report from the Australian Bureau of Meteorology and CSIRO*. https://www.csiro.au/en/research/environmental-impacts/climate-change/State-of-the-Climate/Previous/State-of-the-Climate-2020

Commonwealth of Australia 2022, *State of the climate 2022. A report from the Australian Bureau of Meteorology and CSIRO*. https://www.csiro.au/en/research/environmental-impacts/climate-change/state-of-the-climate

Conroy, G 2012, *The effects of fire and fragmentation upon two threatened coastal heath species, Acacia baueri ssp. baueri (Mimosaceae) and Blandfordia grandiflora (Blandfordiaceae),* PhD thesis, University of Sunshine Coast.

Crowley, GM, Garnett, ST. and Shephard, S 2004, *Management guidelines for golden-shouldered parrot conservation*, Technical Guideline, Queensland Parks and Wildlife Service, Brisbane.

Crowley, G, Garnett S and Shephard, S 2009, 'Impact of storm-burning on *Melaleuca viridiflora* invasion of grasslands and grassy woodlands on Cape York Peninsula, Australia', *Austral Ecology*, vol. 34, 196–209.

DAWE 2022, *Fire regimes that cause declines in biodiversity as a key threatening process*, Department of Agriculture, Water and the Environment, Canberra, April

Department of Climate Change, Energy, the Environment and Water (DCCEEW) 2022, *Conservation advice for Petauroides volans (greater glider (southern and central))*.

Department of Environment and Heritage Protection (DEHP) 2017a, *Guidelines for managing fire in northern bettong (Bettongia tropica) habitat*, Queensland Government, Brisbane.

Department of Environment and Heritage Protection (DEHP) 2017b, *Field guide for managing fire in northern bettong habitat*, Queensland Government, Brisbane.

Department of Environment and Science 2021, *First Nations co-design planning guide*, version 1, Queensland Government. Internal document.

Department of Environment and Resource Management (DERM) 2012, *QPWS Planned Burn Guidelines: how to assess if your burn is ready to go*, Queensland Government, Brisbane.

Department of Environment and Conservation (DEC) 2004, *Old growth forests. Natural Resource Management Advisory Series*, note 10.

Dixon, KM, Cary, GJ, Worboys, GL and Gibbons, P 2018, 'The disproportionate importance of long-unburned forests and woodlands for reptiles', *Ecology and Evolution*, vol. 8, 10952–10963.

Dowdy, A, Brown, A, Pepler, A, Thatcher, M, Rafter, T, Evans, J, Ye, H, Su, C, Bell, S and Stassen, C 2021a, *Extreme temperature, wind and bushfire weather projections using a standardised method*, Bureau Research Report No. 055, Bureau of Meteorology, Australian Government.

Dowdy, A, Thatcher, M, Rafter, T, Evans, J, Ye H, Su C, Stassen C, Pepler A, Bell S and Steinle P 2021b, *Extreme bushfire projections for Australia using a standardised method*, 24th International Congress on Modelling and Simulation, Sydney, New South Wales, Australia, 5–10 December 2021.

Ellis, S, Kanowski, PRW and Whelan, R 2005, *National inquiry on bushfire mitigation and management*, Council of Australian Governments Report, Commonwealth of Australia, Canberra.

Eyre, TJ, Butler, DW, Kelly, AL and Wang, J 2010, 'Effects of forest management on structural features important for biodiversity in mixed-age hardwood forests in Australia's subtropics', *Forest Ecology and Management*, vol. 259, 534–546.

Eyre, TJ, Kelly, AL, Neldner, VJ, Wilson, BA, Ferguson, DJ, Laidlaw, MJ and Franks, AJ 2015, *BioCondition: a condition assessment framework for terrestrial biodiversity in Queensland. Assessment manual*, version 2.2, Queensland Herbarium, Department of Science, Information Technology, Innovation and Arts, Brisbane.

Eyre, TJ, Smith, GC, Venz, MF, Mathieson, MT, Hogan, LD, Starr, C, Winter, J and McDonald, K 2022, *Guide to greater glider habitat in Queensland*, report prepared for the Department of Agriculture, Water and the Environment, Canberra. Department of Environment and Science, Queensland Government, Brisbane.

Ezzy, L 2022 online, 'Breaking the wildfire cycle: progressive fire management can shift fire regimes and improve ecosystem condition – a case study from a large conservation reserve in northern Australia', *Rangelands Journal*.

Falster, C, Gallagher, R, Wenk, EH, et al. 2021 , AusTraits, a curated plant trait database for the Australian flora. *Scientific Data*, vol. 8, article 254.

Feary, S 2020, 'Indigenous Australians and fire in south-eastern Australia', in Leavesley A, Wouters M and Thornton R 2020, *Prescribed burning in Australasia: the science, practice and politics of burning the bush*, Australasian Fire and Emergency Service Authorities Council Limited, Melbourne, Victoria.

Fensham, RJ and Radford-Smith, J 2021, 'Unprecedented extinction of tree species by fungal disease', *Biological Conservation*, vol. 261, 109276.

Flanagan-Moodie, AK, Holland, GJ, Clarke, MF and Bennett, AF 2018, 'Prescribed burning reduces the abundance of den sites for a hollow-using mammal in a dry forest ecosystem', *Forest Ecology and Management*, vol. 429, 233–243.

Garnett, ST and Crowley, GM 2002, *Recovery plan for the golden-shouldered parrot Psephotus chrysopterygius 2003–2007*, Report to Environment Australia, Canberra. Queensland Parks and Wildlife Service, Brisbane.

Gibbons, P and Lindenmayer, D 2002, *Tree hollows and wildlife conservation in Australia*, CSIRO Publishing, Collingwood, Victoria.

Gill, AM 1975, 'Fire and the Australian flora: a review', *Australian Forestry*, vol. 38, 4–25.

Gill, AM and Bradstock, RA 1992, 'A national register for the fire responses of plant species', *Cunninghamia*, vol. 2, 653–660.

Gill, AM, Bradstock, RA and Williams, JE 2002, 'Fire regimes and biodiversity: legacy and vision', in Bradstock, RA, Williams, JE & Gill, MA eds. 2002, *Flammable Australia. The fire regimes and biodiversity of a continent*, Cambridge University Press.

Gill, AM, Groves, RH and Noble, IR eds. 1981, *Fire and the Australian biota*, Australian Academy of Science, Canberra.

Griffith, SJ and Rutherford, S 2020, 'Flowering of *Blandfordia grandiflora* (Christmas bells) in response to fire frequency and temperature', *Australian Journal of Botany*, vol. 68, 449–457.

Harrington, GN and Murphy, SA 2015, 'The distribution and conservation status of Carpentarian grasswrens (*Amytornis dorotheae*), with reference to prevailing fire patterns', *Pacific Conservation Biology*, vol. 21, 291–297.

Hines, F, Tolhurst, KG, Wilson, AAG and McCarthy, GJ 2010, *Overall Fuel Hazard Assessment Guide*, 4th edition, Fire and Adaptive Management Report no. 82, Victorian Government, Department of Sustainability and Environment, Melbourne.

Hines, HB, Brook, M, Wilson, J, McDonald, WJF and Hargreaves, J 2020, 'The extent and severity of the Mackay highlands 2018 wildfires and the potential impact on natural values, particularly in the mesic forests of the Eungella-Crediton area', *Proceedings of the Royal Society of Queensland*, vol. 125, 139–157.

Hines, HB, Meyer, EA and Hetherington, S 2015, 'First Queensland records of the heath shadeskink (*Saproscincus oriarus*)', *The Queensland Naturalist*, vol. 53, 37–45.

House, A, Cook, J and Barrett, T 1998, 'Crediton burning: rainforest recovery after fire in the Clarke Range, Queensland' in *Working Papers – Seventh Queensland Fire Research Workshop*, Cairns, 1–3 July 1998, Toowoomba, Land Use Study Centre, University of Southern Queensland, 39–48.

Hradsky, BA, Mildwater, C, Ritchie, EG, Christie, F and Di-Stefano, J 2017, 'Responses of invasive predators and native prey to a prescribed forest fire', *Journal of Mammalogy*, vol. 98, 835–847.

Hradsky, BA 2020, 'Conserving Australia's threatened native mammals in predator-invaded, fire-prone landscapes', *Wildlife Research*, vol. 47,1–15.

Jones, GM and Tingley, MW 2022, 'Pyrodiversity and biodiversity: a history, synthesis, and outlook', *Diversity and Distributions*, vol. 28, 386–403.

Laidlaw, MJ and Butler, DW 2021, *Potential habitat modelling methodology for Queensland*, version 2.0, updated November 2021, Queensland Herbarium, Queensland Department of Environment and Science, Brisbane.

Laidlaw, MJ, Hines, HB, Melzer, RI and Churchill, TB 2022, 'Beyond bushfire severity: mapping the ecological impact of bushfires on the Gondwana Rainforests of Australia World Heritage Area', *Australian Zoologist*, vol. 42, 502–513.

Lamb, D, Loyn, R, Smith, A and Wilkinson, G 1998, *Managing habitat trees in Queensland forests: a report by the habitat tree technical advisory group to the Queensland Department of Natural Resources*, *Forest Resources*. Queensland Government and the Department of Natural Resources.

Lamont, BB and Downes, KS 2011, 'Fire-stimulated flowering among resprouters and geophytes in Australia and South Africa', *Plant Ecology*, vol. 212, 2111–2125.

Leahy, L, Legge, SM, Tuft, K, McGregor, HW, Barmuta, LA, Jones, ME and Johnson, CN 2015, 'Amplified predation after fire suppresses rodent populations in Australia's tropical savannas', *Wildlife Research*, vol. 42, 705–716.

Legge, S, Smith, JG, James, A, Tuft, KD, Webb, T and Woinarski, JCZ 2019, 'Interactions among threats affect conservation management outcomes: livestock grazing removes the benefits of fire management for small mammals in Australian tropical savannas', *Conservation Science and Practice*, vol. 1, e52.

Low, T 2011, *Climate change and terrestrial biodiversity in Queensland*, Department of Environment and Resource Management, Queensland Government, Brisbane.

Macinnis-Ng, C and Eamus, D 2009, *The increasing density of shrubs and trees across a landscape*, University of Technology, Sydney, research report no. 3, Australian Government, Land & Water Australia.

Mackey, B, Berry, S, Hugh, S, Ferrier, S, Harwood, TD and Williams KJ 2012, 'Ecosystem greenspots: identifying potential drought, fire and climate-change micro-refuges', *Ecological Applications*, vol. 22, 1852–1864.

Makinson, RO 2018, *Myrtle rust reviewed: the impacts of the invasive plant pathogen Austropuccinia psidii on the Australian environment*, Plant Biosecurity Cooperative Research Centre, Canberra.

Makinson, RO, Pegg, GS and Carnegie, AJ 2020, *Myrtle rust in Australia – a national action plan*, Australian Plant Biosecurity Science Foundation, Canberra, Australia.

Manea, A and Leishman, MR 2019, 'The resprouting response of co-occurring temperate woody plant and grass species to elevated CO_2: an insight into woody plant encroachment of grasslands', *Austral Ecology*, vol. 44, 917–926.

McFarland, DC 1991a, 'The biology of the ground parrot, *Pezoporus wallicus*, in Queensland. II. Spacing, calling and breeding behaviour', *Wildlife Research*, vol. 18, 185-197.

McFarland, DC 1991b, 'The biology of the ground parrot, *Pezoporus wallicus*, in Queensland. III. Distribution and abundance', *Wildlife Research*, vol. 18, 199–213.

McGregor, HW, Legge, S, Jones, ME and Johnson, CN 2014, 'Landscape management of fire and grazing regimes alters the fine-scale habitat utilisation by feral cats', *PLoS ONE*, vol 9, e109097.

McGregor, HW, Legge, S, Jones, ME and Johnson CN 2016, 'Extraterritorial hunting expeditions to intense fire scars by feral cats', *Scientific Reports*, vol. 6, 22559.

McLean, CM, Kavanagh, RP, Penman, T and Bradstock, R 2018, 'The threatened status of the hollow dependent arboreal marsupial, the greater glider (*Petauroides volans*), can be explained by impacts from wildfire and selective logging', *Forest Ecology and Management*, vol. 415, 19–25.

McMullan-Fisher SJM, May, TW, Robinson, RM, Bell, TL, Lebel, T, Catcheside, P and York, A 2011, 'Fungi and fire in Australian ecosystems: a review of current knowledge, management implications and future directions', *Australian Journal of Botany*, vol. 59, 70–90.

Meredith, CW, Gilmore, AM and Isles, AC 1984, 'The ground parrot (*Pezoporus wallicus* Kerr) in south-eastern Australia: a fire adapted species?', *Australian Journal of Ecology*, vol. 9, 367–380.

Melzer, R 2015, 'When is stock grazing an appropriate 'tool' for reducing *Cenchrus ciliaris* (buffel grass) on conservation reserves?', *Proceedings of the Royal Society of Queensland*, vol. 120, 53–68.

Melzer R 2019, *Natural Values Health Checks. A guide to undertaking Health Checks for key natural values*, version 1.8, August 2021. Ecological Assessment Unit, Queensland Parks and Wildlife Service and Partnerships, Department of Environment and Science, Queensland Government.

Melzer R. 2022, *Using Health Checks as a monitoring tool for pest and fire programs – a guide*. Ecological Assessment Unit, Queensland Parks and Wildlife Service & Partnerships, Department of Environment and Science, Queensland Government.

Melzer, R, Ezzy, L and Hines, HB 2019, 'Health Checks: a simple tool for assessing the condition of values and effectiveness of reserve management', *PARKS*, vol. 25, 67–78.

Miller, RG, Tangney, R, Enright, NJ, Fontaine, JB, Merritt, DJ, Ooi, MKJ, Ruthrof, KX and Miller, BP 2019, 'Mechanisms of fire seasonality effects on plant populations', *Trends in Ecology and Evolution*, vol. 34, 1104–1117.

Moore, N, Barrett, S, Howard, K, Craig, MD, Bowen, B, Shearer, B and Hardy G 2014, 'Time since fire and average fire interval are the best predictors of *Phytophthora cinnamomi* activity in heathlands of south-western Australia, *Australian Journal of Botany*, vol. 62, 587–593.

Moran, C and Boulter, S 2018, *Biodiversity and ecosystems climate adaptation plan*, Queensland Government, Brisbane, Australia.

Morgan, JW and Lunt, ID 1999, 'Effects of time-since-fire on the tussock dynamics of a dominant grass (*Themeda triandra*) in a temperate Australian grassland', *Biological Conservation*, vol. 88, 379–386.

Neldner, VJ, Niehus, RE, Wilson, BA, McDonald, WJF, Ford, AJ and Accad, A 2021, *The vegetation of Queensland. Descriptions of broad vegetation groups*, version 5.0, Queensland Herbarium, Department of Environment and Science.

Noble, IR and Slatyer, RO 1980, 'The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances', *Vegetation*, vol. 43, 5–21.

Pegg, G, Shuey, L, Giblin, F, Price, R, Entwistle, P, Carnegie, A, McTaggart A and Firn, J 2021, *Fire and rust – impact of myrtle rust on post-fire regeneration*, NESP Threatened Species Recovery Hub Project 8.3.5 update report, Brisbane.

Pyke, GH 2017, 'Fire-stimulated flowering: a review and look to the future', *Critical Reviews in Plant Sciences*, vol. 36, 179–189.

Queensland Parks and Wildlife Service (draft) 2020, *Procedural Guide – Guide to determining the need for post-bushfire evaluation of impacts on key and other significant natural values to inform future management*. (internal)

Queensland Parks and Wildlife Service and Partnerships (QPWS&P) 2021, *Bushfire Risk Management Framework*, Department of Environment and Science.

Queensland Fire and Emergency Services 2020, *Queensland Bushfire Plan*, Queensland Government, Brisbane.

Queensland Parks and Wildlife Service 2012, *Fire operations field guide – personal training and experience log*, version 3, Queensland Government, Brisbane.

Radford, IJ, Corey, B, Carnes, K, Shedley, E, McCaw, L and Wooley, L 2021, 'Landscape-scale effects of fire, cats, and feral livestock on threatened savanna mammals: unburnt habitat matters more than pyrodiversity', *Frontiers in Ecology and Evolution*, vol. 9, article 739817.

Radford, IJ and Andersen, AN 2012, ‘Effects of fire on grass-layer savanna macroinvertebrates as key food resources for insectivorous vertebrates in northern Australia’, *Austral Ecology*, vol. 37, 460–469.

Radford, IJ, Woolley, L, Corey, B, Vigilante, T, Wunambal Gaamber Aboriginal Corp., Hatherley, E, Fairman, R, Carnes, K and Start, AN 2020, ‘Prescribed burning benefits threatened mammals in northern Australia’, *Biodiversity and Conservation*, vol. 29, 2985–3007.

Rose, R, Wiltshire, G and Lang, S 1999, ‘The importance and application of spatial patterns in the management of fire regimes for the protection of life and property and the conservation of biodiversity’, in *Proceedings of the Australian Bushfire Conference – Bushfire ’99*, Albury, New South Wales, 7-9 July 1999, 349–358.

Santos, JL, Hradsky, BA, Keith, DA, Rowe, KC, Senior, KL, Sitters, H and Kelly, LT 2022, ‘Beyond inappropriate fire regimes: a synthesis of fire-driven declines of threatened mammals in Australia’, *Conservation Letters*, e12905.

Saunders, ME, Barton, PS, Bickerstaff, JRM, Frost, L, Latty, R, Lessard, BD, Lowe, EC, Rodriguez, J, White, TE and Umbers, KDL 2021, ‘Limited understanding of bushfire impacts on Australian invertebrates’, *Insect Conservation and Diversity*, vol. 14, 285–293.

Shaw, RE, James, AI, Tuft, K, Legge, S, Cary, GJ, Peakall, R and Banks, SC 2021, ‘Unburnt habitat patches are critical for survival and in situ population recovery in a small mammal after fire’, *Journal of Applied Ecology*, vol. 58, 1325–1335.

Snyman, HA, Ingram, LJ and Kirkman, KP 2013, ‘*Themeda triandra*: a keystone grass species’, *African Journal of Range and Forage Science*, vol. 30, 99–125.

Spassiani, A 2020, *Climatology of severe convective wind gusts in Australia*, PhD thesis, School of Civil Engineering, The University of Queensland.

Stoetzel, HJ, Leseberg, NP, Murphy, SA, Andrew, ME, Plant, KJ, Harrington, GN and Watson, JE 2020, ‘Modelling the habitat of the endangered Carpentarian Grasswren (*Amytornis dorotheae*): the importance of spatio-temporal habitat availability in a fire-prone landscape’, *Global Ecology and Conservation*, vol. 24, e01341.

Stone, ZL, Maron, M and Tasker, E 2022, ‘Reduced fire frequency over three decades hastens loss of the grassy forest habitat of an endangered songbird’, *Biological Conservation*, vol. 270, 109570.

Syktus, J, Trancoso, R, Ahrens, D, Toombs, N and Wong, K 2020, *Queensland future climate dashboard: downscaled CMIP5 climate projections for Queensland*. https://www.longpaddock.qld.gov.au/qld-future-climate

Threatened Species Scientific Committee (TSSC) 2016a, *Conservation advice Amytornis dorotheae Carpentarian grasswren*, Canberra, Department of the Environment.

Threatened Species Scientific Committee 2016b, *Conservation advice Bettongia tropica northern bettong*, Canberra, Department of the Environment and Energy.

Threatened Species Scientific Committee (TSSC) 2017, *Conservation advice Psephotus chrysopterygius (golden-shouldered parrot, alwal)*, Canberra, Department of the Environment and Energy.

Tuft, KD, Crowther, MS and McArthur, C 2012, ‘Fire and grazing influence food resources of an endangered rock-wallaby’, *Wildlife Research*, vol. 39, 436–445.

Verdon, SJ and Clarke, MF 2022, ‘Can fire-age mosaics really deal with conflicting needs of species? A study using population hotspots of multiple threatened birds’, *Journal of Applied Ecology*, vol. 59, 2128–2141.

Virkki, DA 2014, *Faunal and floral community responses to contemporary fire regimes in eucalypt forests of southeast Queensland*, PhD thesis, Griffith University, Queensland.

von Takach, B, Jolly, CJ, Dixon, KM, Penton, CE, Doherty, TS and Banks, SC 2022, ‘Long unburnt habitat is critical for the conservation of threatened vertebrates across Australia’, *Landscape Ecology*, vol. 37, 1469–1482.

Whelan, RJ, Rodgerson, L, Dickman, CR and Sutherland, E 2002, ‘Critical life cycles of plants and animals: developing a process-based understanding of population changes in fire-prone landscapes’, in: Bradstock et al. eds. 2002, *Flammable Australia. The fire regimes and biodiversity of a continent*, Cambridge University Press.

Whitehead, PJ, Bowman, DMJS, Preece, N, Fraser, F and Cooke, P 2003, ‘Customary use of fire by indigenous peoples in northern Australia: its contemporary role in savanna management’, *International Journal of Wildland Fire*, vol. 12, 415–425.

Williams, RJ, Bradstock, RA, Cary, GJ, Enright, NJ, Gill, AM, Liedloff, AC, Lucas, C, Whelan, RJ, Andersen, AN, Bowman, DJMS, Clarke, PJ, Cook, GD, Hennessy, KJ and York, A 2009, *Interactions between climate change, fire regimes and biodiversity in Australia – a preliminary assessment*, report to the Department of Climate Change and Department of Environment, Water, Heritage and the Arts, Canberra.

Williams, PR, Congdon, RA, Grice, AC, and Clarke PJ 2004, ‘Soil temperature and depth of legume germination during early and late dry season fires in a tropical eucalypt savanna of north-eastern Australia’, *Austral Ecology*, vol. 29, 258–263.

Williams, PR, Centurino, P and Parsons, M 2017, ‘The fire ecology of *Allocasuarina littoralis* and *Banksia plagiocarpa* in montane heath of the southern Wet Tropics’, *North Queensland Naturalist*, vol. 47, 43–48.

Williams, P, McMahon, K, Collins, E, Grice, T, Mack, A, Marshall, L and Owbridge, E 2020, ‘Black-throated finch habitat values promoted by patchy fire’, *North Queensland Naturalist*, vol. 50, 38–43.

Wilson, AAG 1992, *Assessing the fire hazard on public lands in Victoria: fire management needs and practical research objectives*, research report no. 31, Fire Management Branch, Department of Conservation and Environment, Victoria.

Woinarski, JCZ and Recher, HF 1997, ‘Impact and response: a review of the effects of fire on the Australian avifauna’, *Pacific Conservation Biology*, vol. 3, 183–205.

Wright, BR, Laffiner, B, Roye, D, Armstrong, G and Fensham, RJ 2021, ‘Rainfall-linked megafires as innate fire regime elements in arid Australian spinifex (*Triodia* spp.) grasslands’, *Frontiers in Ecology and Evolution*, vol. 9, article 666241.

York, A and Lewis, T 2018, ‘Understanding the effects of fire on invertebrates in Australian temperate and sub-tropical forests: the value of long-term experiments’, *Australian Zoologist*, vol. 39, 633–645.

8 Glossary

Term	Definition
Backing fire	A fire which is burning back against the wind or down slope, where flame height, intensity and rate of spread are reduced.
Burn extent	A polygon that includes all the areas burnt during a fire event. It includes any remaining unburnt patches within the polygon.
Bushfire	An unplanned vegetation fire (sometimes referred to as wildfire).
Deep-seated fire	A fire burning below the surface in duff (the decomposing vegetative matter below the leaf litter), mulch, peat or other combustible material.
Ecosystem	A biological community of interacting organisms and their physical environment.
Ecosystem-changing weeds	Weeds with the potential to alter ecosystem structure, composition and function and/or affect the ability to manage fire for ecological purposes.
Ecotone	The transition area between two different plant communities (e.g. rainforest and eucalypt forest).
Fire-adapted ecosystem	An ecosystem requiring fire for its ongoing persistence and health. Species that occur in these ecosystems typically have characteristics that help them to survive fire (e.g. thick bark protecting epicormic buds) and regenerate rapidly after fire (e.g. soil protected rootstock, bulbs, rhizomes, soil seed bank, lignotubers). Some species in these ecosystems also require periodic fire for regeneration (e.g. heat-triggered seed release or germination). Fire-adapted communities are not adapted to all fire regimes. Some fire-adapted communities and species have a broader tolerance to fire regimes than others.
Fire frequency	The number of fires that occur at a specific point in the landscape within a specific period; how often fire occurs at a point in the landscape. Refer to fire interval.
Fire history	The history of fire, or how the fire regime has occurred over space and time, within an ecosystem.
Fire intensity	The energy output of a fire. It is measured in kilowatts of energy released per metre ($kW\ m^{-1}$).
Fire interval	The time in years between fires. Also referred to as the between-fire-interval. It is one way of measuring fire frequency and perhaps the most appropriate in an ecological sense because it allows direct insight into consequences for time-dependent life history processes.
Fire regime	The sequence of fires at a point in the landscape, consisting of the components: fire frequency (or fire interval, between-fire interval), intensity, season and type (e.g. surface versus subterranean/peat fire).
Fire-sensitive ecosystem	An ecosystem that does not require fire to maintain it or its species. It may be destroyed or degraded by fire, often taking decades to centuries to recover in the absence of further fire. Many plant species that occur in these ecosystems are killed by fire. Some can resprout from the base after fire.
Fire severity	The observable effect on the vegetation, such as the degree of scorching or consumption of the litter layer, mid-layer and canopy. Fire severity classes incorporate fire intensity, as well as average flame height and the physical effect of the fire on vegetation and soil. Fire severity classes are provided in DERM 2012 *QPWS Planned Burn Guidelines: how to assess if your burn is ready to go* (internal)
FLAME	QPWS's web-based system for capturing basic fire (and pest) information including burn proposals, burn plans (approved burn proposals) and reports and associated maps.

Term	Definition
Forb	An herbaceous flowering plant that is not a grass, sedge or rush.
Fuel hazard	The condition of the fuel taking into consideration such factors as quantity, arrangement, current or potential flammability and the difficulty of suppression if fuel should be ignited (Wilson 1992). A method for assessing fuel hazard is provided in Hines et al. 2010 *Overall Fuel Hazard Assessment Guide*. (external)
Fuel load	The dry weight of combustible materials per area, usually expressed as tonnes per hectare; a quantification of fuel load does not describe how the fuel is arranged or its state or structure (Hines et al. 2010). A method for estimating fuel load is provided in DERM 2012 *QPWS Planned Burn Guidelines: how to assess if your burn is ready to go* (internal)
Herb	An herbaceous (non-woody), seed-bearing plant.
High intensity fires	Fires that occur when there is low humidity and strong winds (often accompanied by high temperatures) and high, cured fuel loads. They are typically fast-moving and result in high scorch and consumption heights and a more thoroughly combusted ground layer. They have greater direct and indirect impacts on wildlife than lower intensity fires.
Levels of Service (LoS)	a planning tool in the Values-Based Management Framework used to identify the acceptable management standard, or level of resourcing, that is required to maintain an area based on its values, threats and complexity of management.
Long unburnt	Where a portion of an ecosystem has a fire interval longer than generally recommended for the ecosystem. Long unburnt ecosystems typically have mature to overmature vegetation and complex litter layers. The structure and/or composition of habitats found in long unburnt vegetation is extremely important for some species. For example, patches of old spinifex in southwest Queensland hummock grasslands are critical habitat for the endangered night parrot *Pezoporus occidentalis*. The length of time that constitutes 'long unburnt' is relative to the ecosystem. The REDD provides fire interval guidance for some ecosystems.
Low intensity fires	Wires that travel slowly and typically result in patchy burns, cause little or no crown scorch and remove less ground litter. These fires limit potential negative impacts of burning, such as loss of fauna habitat and post-fire soil erosion.
Mosaic	Used in the context of fire management it is the spatial distribution of vegetation burnt (by planned burn and bushfire) at varying fire histories. When used in the context of a single burn, it relates to the spatial variation of burn intensity and the size, shape and connectivity of unburnt patches. With successive fires the mosaic becomes increasingly complex. Refer to mosaic burning.
Mosaic burning	An approach that aims to create spatial and temporal variation in fire regimes. It includes spatial variation within individual burns. See Box 3.1, sections 3.3, 5.4.1, 5.4.3 and Appendix 3 for detailed discussion.
Natural value	The ecosystems and species in a park or forest.
Obligate seeders (obligate seed regenerators)	Plants where adults are killed by fire and their only means of regeneration is from soil or canopy stored seed.

Term	Definition
Old growth	Wooded ecosystems (e.g. woodlands, open forests, forests) where the overstorey is in the late-mature to over-mature (senescent or partly dying) growth stage. They contain large old trees (relative to the ecosystem), many with hollows in trunks and branches. Fallen trees (logs) are usually present, and dead standing trees may also be present. There is little evidence of disturbance, such as timber harvesting. Where some disturbance occurs, such as fire or storm, the impact has minimal effect on the old growth characteristics of the ecosystem. Old-growth ecosystems are extremely important in maintaining biodiversity and ecological functions. DEC (2004). (external)
Peat	An amorphous (lacking shape) organic material formed by the anaerobic (no oxygen) decomposition of vegetation. It usually occurs in areas that are seasonally or permanently inundated with water.
Peat fire	A type of deep-seated fire that occurs in peat. It burns by smouldering combustion and generates large amounts of energy per unit area. They cause serious ecological harm.
Planned burning	(Also referred to as prescribed burning) is defined by the Australasian Fire and Emergency Services Authorities Council as the controlled application of fire under specified environmental conditions to a predetermined area and at the time, intensity and rate of spread required to attain planned resource management objectives.
Pyrodiversity	The outcome of complex interactions and feedbacks between fire regimes, biodiversity and ecosystems. Note that an increase in the diversity of fire regimes does not necessarily lead to an increase in biodiversity.
QPWS-managed estate	Lands managed by QPWS, such as parks (national parks, conservation parks and resources reserves) under the *Nature Conservation Act 1992* and forests (forest reserves, state forests and timber reserves) under the *Forestry Act 1959*. It also includes parcels of land of various tenures managed by QPWS (e.g. acquisitions awaiting gazettal and leasehold lands).
Recruitment	The process by which individuals are added to the population.
Regional Ecosystem (RE)	Vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil. The Regional Ecosystem Descriptions Database (REDD) provides statewide RE mapping and descriptions, including fire management guidelines. (external)
Residence time	The total length of time that the flaming front of a fire occupies one point (also known as the time of flaming combustion).
Resprouter	A plant species that can survive fire and regenerate by the activation of dormant vegetative buds to produce regrowth.
Running fire	A fire running with the wind or upslope, where flame height, intensity and rate of spread are high.
Staged or progressive burning	Planned burning with ignition undertaken over days, weeks or months to achieve the desired outcomes of patchiness and intensity.
Storm-burning	Lighting planned fires after the first wet season rains and when follow-up rain can be reliably expected.
Values-Based Management Framework (VBMF)	An adaptive management framework that incorporates planning, prioritising, doing, monitoring, evaluating and reporting into all areas of QPWS work, including fire management for ecological purposes.
Woody thickening	Increased density of woody plants, often in the understorey. It also includes encroachment of tree species into grass, sedge, forb or heath lands or rainforest species into adjacent sclerophyll communities.

8.1 Abbreviations

AFMG:	Area Fire Management Group
AS:	Australian Standard
BRMF:	QPWS Bushfire Risk Management Framework
DES:	Department of Environment and Science
FFDI:	Forest Fire Danger Index
ISO:	International Organization for Standardization
KBDI:	Keech Byram Drought Index
LSFMG:	Locality Specific Fire Management Group
NAFI:	Northern Australia and Rangelands Fire Information
QBP:	Queensland Bushfire Plan
QFES:	Queensland Fire and Emergency Services
QPWS:	Queensland Parks and Wildlife Service
QPWS&P:	Queensland Parks and Wildlife Service and Partnerships
RE:	Regional Ecosystem (see Glossary)
REDD:	Regional Ecosystem Descriptions Database (see Regional Ecosystem in Glossary)
SMERF:	Savanna Monitoring and Evaluation Reporting Framework
VBMF:	Values-Based Management Framework (see Glossary)

Appendix 1. Queensland Parks and Wildlife Service and Partnerships Fire Management Framework and associated drivers and arrangements

(From the QPWS Fire Management Strategy 2021–2026)

The Values-Based Management Framework informs the selection, management and monitoring of values, in particular key values. It also addresses the custodial obligations of fire management.

The Bushfire Risk Management Framework is used during the development of park and forest fire strategies. It helps evaluate risk to assets associated with QPWS-managed estate and surrounds. It also informs strategic directions and actions, including planned burn programs.

Disaster Management Arrangements	QPWS&P Fire Management Framework	DES Management Drivers
Qld Disaster Management Plan	*Nature Conservation Act 1992, Forestry Act 1959*	DES Strategic Plan
Queensland Bushfire Plan	QPWS&P Fire Management Strategy	Master Plan for Queensland's parks and forests
DES Disaster Management	QPWS&P Fire Management Plan *(under development)*	Park and Forest Management Plan/Statement
	Regional Fire Management Plan *(to be developed)*	The Gurra Gurra Framework
	Park and Forest Fire Strategy	Qld Protected Area Strategy
	Planned Operations	Qld Biodiversity Strategy
	Preparedness, Response and Recovery	Qld Climate Adaptation Strategy
	Fire Policy Bushfire Risk Management Framework (BRMF) Planned Burn Guidelines Systems and Mapping Capacity and Capability Governance	

Appendix 2. Creating a VBMF Standard Report for a park or forest

Science Information Services, in collaboration with the Ecological Assessment Unit, has developed a VBMF Standard Report that provides RE and BVG maps and descriptions, lists of significant taxa recorded in the park or forest and modelled potential habitat for significant species that occur or are predicted to occur there. The report is available through the LANDS network at the *Encompass website* (Intranet – Tools and Applications – Environmental & Licencing – encompass). http://encompass/

To generate a report, follow the below instructions:

- Click the link above to access Encompass.
- Scroll down to find, click and open 'Maps Online request form'.
- In the 'Filter by theme' box, select 'All reports'.
- In the 'Report Type' box, click in the box then scroll down to select 'QPWS Values-Based Management Framework (INTERNAL)'.
- In the 'Feature type' box, click in the box and select 'Protected Areas'. Note, this option includes state forests.
- In the 'Protected Area Name' field, start typing the tenure name and choose from the listed options. Then, click the blue 'Add selection' button. Repeat to add more areas to the report.
- Once all areas have been selected, click the green 'Request 1 Report' button. Fill in your email details then select the blue 'Request' form button

The report, including various tables, maps and explanations, will be emailed to you as a PDF.

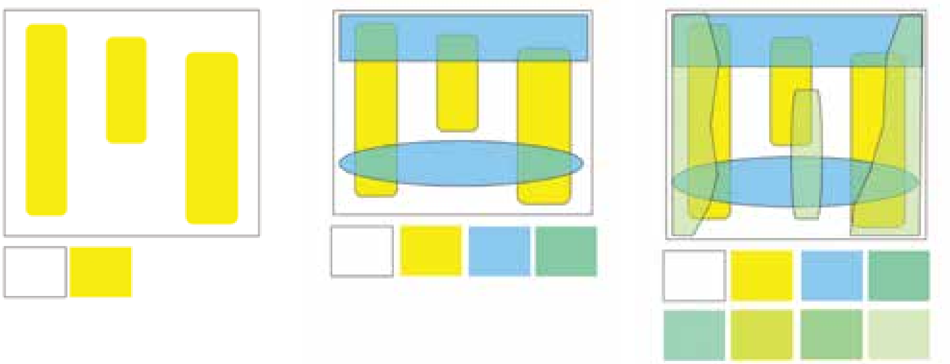
Appendix 3. Mosaic burning

Mosaic burning is the use of planned burns to create a patchwork of areas burnt at different frequencies, with different intensities and in different seasons, within the tolerance of ecosystems.

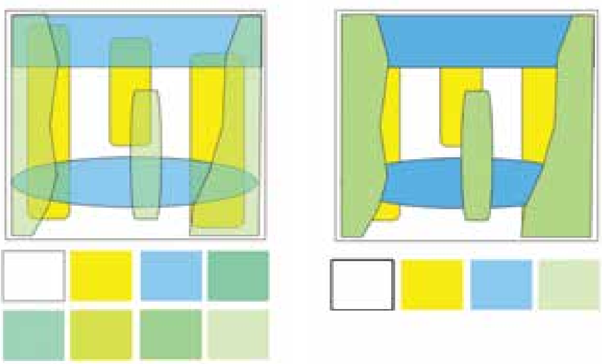
The example below uses the fire frequency component of a mosaic to illustrate the principle.

The maps (Burn 1, 2, 3) show the creation of a simplified mosaic in an area with no prior fire history information. Portions of burns overlay each other, contributing to an increasingly complex history of visible and invisible mosaics. These are depicted by the coloured squares below each map. After only three planned burns, a mosaic of eight different fire frequencies has been created.

Burn 1 **Burn 2** **Burn 3**



Fire history is sometimes considered only in the context of 'time since last burn' and consequently, valuable information about the mosaic is lost. Comparison of the maps below illustrates the difference between a map (left) showing the visible and invisible parts of the mosaic and a map (right) showing only 'time since last burn.'



Mosaic burning, Boodjamulla National Park. *Photo: Lea Ezzy © Qld Govt.*

Sulphur-crested cockatoo *Cacatua galerita*. *Photo: © Rhonda Melzer.*