a program of Healthy land & water

Living with fire

INFORMATION BOOKLET 1

AN INTRODUCTION TO FIRE ECOLOGY

Ecological burn at Primley St Park, Pullenvale, July 2019 (M. Nash, Brisbane City Council). An ecological burn is a type of planned burn of native vegetation for the preservation or enhancement of ecological processes and biodiversity values.

Fire ecology is the study of the role of fire in an ecosystem. In particular, how fire interacts with plants, animals, fungi, and soil. Fire ecology provides essential insights for the management of forests, water catchments, soils, biodiversity, agriculture and natural resources, amongst other ecological processes (e.g. pollination). Through the use of fire, Traditional Owners have, and continue to play a significant role in the biodiversity conservation of Australian landscapes. This understanding is key for effective land management and biodiversity conservation in our fire-prone environment. In this booklet, we focus on the response of plants and animals to fire and related ecological processes, with particular reference to research and examples from the South East Queensland (SEQ) region.

Fire ecology and management

Fire has played a critical role in the evolution of the Australian landscape, through traditional Aboriginal burning practices for tens of thousands of years and millions of years of lightning strikes (Bradstock *et al*. 2012). Many Australian plant, animal and fungi species have evolved strategies to survive, replenish and take advantage of a fire-prone environment (Whelan 1995). It is therefore not surprising that appropriate fire has an important role to play in maintaining the diversity of native species and ecosystems[1]. Services provided by fire include opening up the canopy (allowing sunlight to reach the ground so new seedlings can grow), triggering flowering and seed germination, and creating hollows in trees and logs. Fire is also a disrupter and high intensity fire can be especially destructive when unplanned (i.e. wildfire) or in poor conditions (e.g. drought).

[1] An ecosystem is '*a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*' (United Nations 1992).

Sedges and herbs flowering 9 months after an ecological burn, Brisbane Koala Bushlands (P. Watson).

Plant strategies to live with fire

Plants and animals living in fire-prone environments have strategies to survive or replenish populations after fire (Whelan 1995; Bradstock *et al.* 2012). However, most species have limits to their tolerance for different aspects of fire, including the frequency of fire, temperature, time of year and patchiness. In particular, too much or too little fire can lead to species decline and even eventual local extinction. These tolerance limits vary between species and communities, with some species needing more, or less fire than others. Subtropical and temperate grassy ecosystems, for example, need quite frequent fire to maintain their open structure, keep dominant grasses healthy, make space for smaller grasses and herbs, and prevent woody plants taking over. This is relevant for species such as the eastern bristlebird, which relies on native grasses. Rainforests, on the other hand, do not need fire, are considered fire-sensitive and benefit from fire exclusion.

Plants in fire-prone ecosystems exhibit a range of strategies for surviving, or even thriving, under various fire regimes (refer page 4). At the level of the individual tree, shrub or herb, some plants survive fire and though damaged, go on to flourish in post-fire conditions. Other individuals die. To compensate for fire-related mortality, burns also trigger processes that produce new plants. Ecologists have explored the different attributes and reproductive responses of plants to fire, the most basic of which is regeneration mode. Regeneration mode refers to the way a plant species regains its place in the community after a fire. Fire-prone plant species are classified as either resprouters, or obligate seeders depending on whether adult plants die when all of their leaves have been scorched (Gill 1981; Whelan 1995).

Obligate seeders

All, or almost all, obligate seeding adult plants (sometimes just called 'seeders') are killed by fire (Whelan 1995). To persist in the community, they rely on regeneration from seed held in soil or canopy-stored seedbanks. The majority of seedlings in most post-fire environments are produced by obligate seeders.

Some species exhibit different regeneration modes in different environments. Examples include the rice flower (*Pimelea linifolia*) – an obligate seeder in most vegetation types, but a resprouter in wet heath (Benwell 1998), and the grass wiry panic (*Entolasia stricta*) – a seeder in rock pavement heath, but a resprouter in surrounding forest (Benwell and McCorkell 2011).


Goodenia bellidifolia flowering 11 months after fire, Mt Banks, the Blue Mountains (*G.bellidifolia subsp. argentea* occurs across SEQ) (P. Watson).

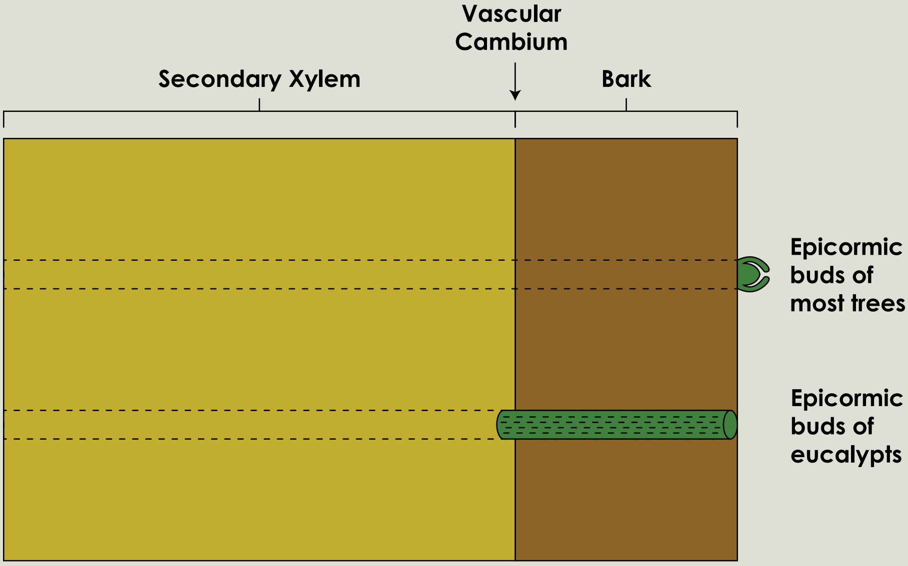

Pimelea linifolia, an obligate seeder in most habitats, resprouts in wet heath (P. Watson).

Since the adult plants of obligate seeding species are largely killed by fire, there must be enough time between fires for new seedlings to grow into seed producing plants, before the population is burnt again. Therefore, these species and populations can be vulnerable to a second fire that occurs too soon after the first. The time from seed germination to first flowering and fruiting is called the species' 'juvenile period'. Because of this vulnerability, management guidelines often set mimimum intervals between fires at, or just above, the juvenile period of the slowest maturing obligate seeder species.

Most obligate seeders in fire-prone communities in SEQ tend to mature quite rapidly, with many shrubs flowering by the third year after fire. In some seeder species, a proportion of plants survive fire because the plant is taller than the height of the scorch from the flames, e.g. Black she-oak (*Allocasuarina littoralis*) and some wattles. Interestingly, these species tend to be ones with longer juvenile periods. Some also have the ability to recruit between fires, or to supress growth of small plants beneath them. As a result they can be highly successful, even weedy, in infrequently burnt areas (Lunt 1998).

Epicormic buds

*In most trees, epicormic buds are located at the surface of the bark (top), a position where they are exposed directly to the heat of a fire. In eucalypts, for each epicormic strand there are several strips of very small cells that run from the bark surface, through the bark and into the wood for a short distance (bottom). These cells can form numerous buds at various depths in the bark after a fire. Thus, even if most of the bark is killed in an intense fire, some of the bud forming cells will still be alive. The dotted lines indicate the epicormic strands, while the green colour indicates that part of the strand where bud regeneration is possible. The dotted lines within the eucalypt strand surrounded by the bark represent the meristem strips.**



Reproduced from Bradstock *et al.* (2012), *Flammable Australia: fire regimes, biodiversity and ecosystems in a changing world*, with permission from CSIRO Publishing.

**The meristem is responsible for plant growth.*

Resprouters

Resprouters generally survive fire, although they may suffer significant damage to their above-ground biomass. Resprouters regenerate by 'resprouting' (i.e. regrowing photosynthetic tissue) via three main means:

- **Epicormic buds**, which lie dormant beneath bark on trunks and stems, are triggered to grow by damage from a fire. Almost all SEQ eucalypts and some other tree and tall shrub species can resprout in this way. Eucalypt buds extend beyond the bark, deep into the wood (refer diagram, page 3). Species with this strategy can quickly regain height and dominance in a post-fire environment.
- **Lignotubers**, woody swellings of the root crown that contain not only protected buds, but a store of starch to support growth of new post-fire stems. Many eucalypts have lignotubers, allowing plants whose stems have been killed to regrow from ground level. Other lignotuberous shrub species routinely resprout from the base, as stems subject to 100% leaf scorch die.
- **Subterranean roots or rhizomes** (underground horizontal stems), allow many grasses, sedges and herbs to resprout. For example, most orchids regrow after fire from underground tubers. Resprouting from horizontal roots or rhizomes potentially allows a species to increase population numbers after a fire. This strategy is also found in some SEQ trees and shrubs, including some rainforest pioneers. Examples include black wattle (*Acacia mearnsii*), celerywood (*Polyscias elegans*) and cheese tree (*Glochidion ferdinandi*). Some resprouters, including some legumes, also produce post-fire seedlings in reasonable numbers. These species are sometimes called 'facultative resprouters'.

Aotus subglauca resprouting from a small lignotuber, 21 months after fire (P. Watson).

Chain fruit (Alyxia ruscifolia) resprouting from roots, seven months after fire, Belmont Hills Reserve, Brisbane (P. Watson).

Recommended fire regimes

Recommended fire regimes establish guidelines for fire management of different vegetation communities (e.g. grasslands, tall open forest), including recommendations for fire frequency, season (time of year), intensity (temperature), and extent (patchiness and spread). Fire regime guidelines aim to accommodate the needs of all species in a community. For more information on recommended fire regimes, see our *Recommended Fire Regimes Information Booklet* (www.fireandbiodiversity.org.au/publications).

While fire frequencies within recommended guidelines should sustain populations of almost all plant and animal species in an ecosystem, a few may need more or less fire. For example, recent modelling suggests that two local, rare coastal heath plants, tiny wattle (*Acacia baueri subsp. bauer*) and Christmas bells (*Blandfordia grandiflora*) would both benefit from return intervals of 3 - 5 years (Conroy 2012). These intervals are shorter than currently recommended for wallum heath (7 - 20 years, with an emphasis on 8 - 12 years). Managing some heathland areas with more frequent fire may therefore be appropriate. Conversely, some fauna species do particularly well in long unburnt patches, so intervals above thresholds may also be appropriate.

Bunya Mountains, Queensland (Burnett Mary Regional Group).

Fire frequency

Fire frequency can have an impact on the ecology of a species or ecosystem. For example, too frequent fire may not leave enough time for obligate seeders to reach maturity, flower and fruit, which allows the creation of a seedbank. Too infrequent fire can also result in serious impacts in fire-prone ecosystems. Plant species that rely on fire for successful reproduction may decline or even become locally extinct. Other plant species may colonise and/or build up in numbers or density, shading out smaller plants. In some situations, a new vegetation layer and ultimately a different vegetation type may develop. For example, in the Bunya Mountains, Traditional Owners, land managers and scientists have documented changes in what were once open grassy 'balds'. Until the early 1900s, frequent Aboriginal burns kept the grassy balds open. Due to a lack of appropriate fire, wattles, eucalypts, and rainforest species have invaded, reducing the extent of these distinctive features (Butler *et al*. 2014). Now, the Bunya Peoples' Aboriginal Corporation is working with the Burnett Mary Regional Group (www.bmrg.org.au), Queensland Parks and Wildlife Service, land managers and scientists to return fire to these grasslands. For more information visit www.facebook.com/bunyarangers4BPAC

Bunya Peoples' Aboriginal Corporation cultural fire workshop, Bunya Mountains, 2017 (D. Currie).

Christmas bells (Blandfordia grandiflora) flowering post fire on the Sunshine Coast (G. Conroy).

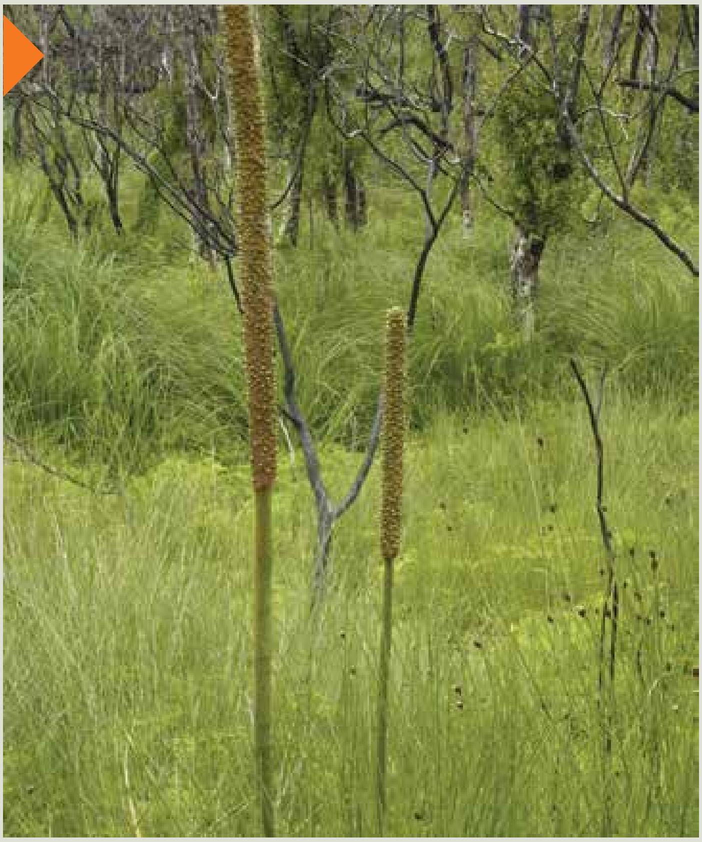
Flourishing in the post-fire environment

Many aspects of the post-fire environment improve opportunities for plant species to replenish their populations through enhanced establishment, survival and growth.

1. Enhanced plant growth

The months and early years after a fire are very conducive to plant growth – particularly once good rain occurs. For surviving plants, competitive pressure from other plants is suddenly reduced, making water and nutrients more available. Insects and other herbivores are temporarily reduced in abundance. Ash beds provide growth-promoting nutrients, and fungal diseases may be less of an issue.

Image right: Lush regrowth, including flowering Xanthorrhoea fulva, in wet heath, 11 months after fire, Minjerribah (North Stradbroke Island) (P. Watson).



2. Improved seedling establishment

Vegetation killed by fire creates space, allowing sunlight to reach ground level, and making water and nutrients more available for new seedlings. These benign conditions help seedlings to establish by reducing competition and providing space for seedlings to get a foothold and grow. This is particularly important for obligate seeders who rely on regeneration after fire from seed stored in seedbanks.

Image left: Hardenbergia violacea seedling emerging five months after fire (this species is common in SEQ) (P. Watson).

3. Seed release and dispersal

Many species that store their seeds in woody capsules exhibit 'serotiny'. This means the cones or capsules in which seeds are stored and protected remain closed until an environmental trigger (in this case fire) forces them to open. This attribute ensures that seeds are released at just the right time to take advantage of post-fire conditions (examples includes banksia and hakea species). Seeds stored on a plant in this way often have 'wings' or other features to help them disperse away from parent plants (Hammill *et al*. 1998). Improved wind flow and less impediments in the more open conditions after a fire enable seeds to travel further.

Image left: Conesticks (Petrophile pulchella) opening 6 months after fire; seeds with 'parachutes' can be seen emerging (P Watson).

4. Germination of soil-stored seeds

Heat from fire cracks the hard seed coats of seeds buried in the soil, allowing water to enter the seed and germination to commence – this is known as physical dormancy. Other dormant seeds are cued to germinate by chemicals called karrikins (an Aboriginal word for smoke), which are found in smoke and ash. Some soil-stored seeds respond to both heat and smoke. Once again, these triggers ensure seedlings emerge at the ideal time. In fact, many obligate seeder shrubs do all, or almost all their recruitment in the window of opportunity provided by fire, developing even-aged stands of plants that grow up together.

Image right: Daviesia wyattiana, an obligate seeder, flowering after fire, Toohey Forest, Brisbane. This species regenerates from a soil-stored seedbank (P. Watson).

5. Post-fire flowering

Some plants flower, or flower more abundantly, in the months or years after a fire. In the ground layer, many grasses and other herbs flower copiously in the year after a fire, producing seed that may germinate and grow while conditions are especially favourable. Christmas bells (*Blandfordia grandiflora*) illustrate this response as peak flowering occurs in the first year after a fire, then declines to almost nothing by four years post fire (Ramsey and Vaughton 1996). Larger plants that flower primarily in the early years after a fire include some grasstrees (*Xanthorrhoea* spp.), the crinkle bush (*Lomatia silaifolia*; Denham and Whelan 2000) and further south from Queensland, the waratah (*Telopea speciosissima*; Denham and Auld 2002).

Image left: Austromyrtus dulcis resprouting and flowering, 11 months after fire, Minjerribah (North Stradbroke Island) (P. Watson).


Banksia robur scorched seed septa with visible seed hollows (where the seed is stored), a burnt seed and one seed septum with the wing singed but the seed unburnt. This photo was taken approximately two months after fire at Coolum, Sunshine Coast (S. Lloyd).

Seedbanks

A seedbank is a store of seeds. The role of the seedbank is to maintain enough seed between fires for the species to regenerate and persist, even when above-ground plants have been killed by the passage of fire (Whelan, 1995). Most plant species store seed in the soil. However, some species store seed on the plants themselves, for example banksias, hakeas and cypress pines store seed in woody fruits. Seeds stored in a seedbank remain dormant until an environmental trigger (predominantly heat from fire) stimulates them to open and allows germination. There are two broad groups of seed dormancy:

- Physical dormancy (all canopy-stored species and some soil-stored species such as acacias and peas).
- Physiological dormancy (only soil-stored species, including species from the Ericaceae, Rutaceae and Apiaceae families).

Approximately two months after a fire at Coolum (Sunshine Coast) this Banksia robur cone has open seed follicles (triggered by fire) and a number of emerging seed septa can be seen (S. Lloyd).

Physiological dormancy

Physiological dormancy is more complicated, with studies showing that the seeds of these species are strongly tied to seasonal temperatures and may be impacted by climate change (Ooi 2010). Often a mix of temperature (e.g. chilling in winter) and smoke from fire are required to break dormancy and cue germination (Mackenzie *et al*. 2016; Collette and Ooi 2017). These triggers ensure seedlings emerge and may take advantage of the (generally) reduced competition and favourable conditions of the post-fire environment.

Seeds may persist in the seedbank for decades, though seed longevity (i.e. how long a seed remains viable, or readily able to germinate in the soil) differs widely between species (Auld *et al*. 2000; Orscheg and Enright 2011). Once flowering and fruiting commences after a fire, seedbanks are replenished via the inclusion of new seeds. Species with soil-stored seedbanks may, or may not, have

Physical dormancy

Seed from the physically dormant group have a hard and impermeable seed coat that requires heat (from fire) to open. Most plants in fire-prone environments have seeds with physical dormancy and once heat has triggered the opening of the seed coat, seed may be released (in the case of seed stored on the plant) and germination can occur (usually after rain). Studies have shown that approximately 80°C represents a temperature that enables a good flush of emergence across a broad range of species. At 120°C, most species do not survive and at the other end of the spectrum, if the temperature is too low then dormancy may not be broken (Auld and O'Connell 1991; Ooi *et al*. 2014).

Plant species with canopy seedbanks (e.g. eucalypts) generally do not have soil-stored seed. Thus, these species only exist from when the plants first start seed production, until the point when adult plants die.

Daviesia villifera seedling, six months after a planned burn, Whites Hill Reserve, Brisbane (P. Watson).

ungerminated seeds left in the ground after the initial pulse of post-fire germination has passed. In later post-fire years, input to the seedbank may decline, or cease altogether, as flowering (and therefore seed production) is reduced in adult plants as they reach old age.

Fauna and fire

Like plants, animal species in fire-prone environments generally have strategies to either survive fire, or to recolonise afterwards. However, animal persistence in fire-prone landscapes and our knowledge of adaptive traits, behaviour and physiological responses in animals to fire remains limited and poorly understood (Stawski *et al*. 2016; Pausas and Parr 2018). While individual animals may die from a fire event, the critical issue is whether locally a species is capable of persisting through not just one fire, but through the series of fires that make up the fire regime. In the face of a single fire, individuals of some fauna species manage to stay alive by getting out of the way of the flames. These species are known as 'avoiders'. Birds, insects and some mammals, such as wallabies, can move out of the area. Other species shelter under the ground or in logs. Research in northern NSW recorded brown antechinus (*Antechinus stuartii*) surviving a planned burn by sheltering in trees above flame height (Stawski *et al*. 2015). Fire intensity will naturally affect survival rates (Robinson *et al*. 2013), as will fire extent, as many animals require unburnt patches for refuge.

Individual animals that survive a fire may face difficulties in its immediate aftermath, due to the sudden removal of food and shelter. Predation can be a particularly pernicious problem as feral predators including cats and foxes may actively target native wildlife in burnt areas (Leahy *et al*. 2015).

In fire-prone landscapes, many animal species have evolved strategies and mechanisms that support adaptation to fire, whereby these animals benefit from a habitat that has evolved with fire. Some of these animals have become specialised and require fire to create the appropriate conditions for growth and reproduction. Other animals, such as raptors, benefit directly from post-fire successional stages (Pausas and Parr 2018).

Some Australian mammals have a unique strategy for coping with the less-than-ideal post-fire environment, the brown antechinus and short beaked echidna (*Tachyglossus aculeatus*) increase the time they spend in 'torpor'[2], reducing their need for energy and avoiding predators (Nowack *et al*. 2016; Stawski *et al*. 2015). Research by Geiser *et al*. 2018 shows that heterothermic animals (i.e. animals that vary between self-regulating their body temperature and taking advantage of the environment and conditions) have an advantage over homeotherms (i.e. animals that maintain a stable internal temperature regardless of the environment) in changing environmental conditions, through their flexible thermal energetics and as a result of the ability to employ daily torpor and longer term hibernation. This is especially true with respect to small mammal response to fire, as heterothermia reduces their energy requirements and exposure to predation, thereby increasing their resilience.

Short beaked echidna (Tachyglossus aculeatus) (Mark Sanders, EcoSmart Ecology).

[2] Mammalian torpor is characterised by a substantial and controlled reduction in body temperature, metabolic rate and water loss for less than 24 hours, accompanied by inactivity and absence of locomotion (Geiser 2004).

Fauna and vegetation recovery

Once vegetation starts to regrow, resources for animals become more available. Population numbers of some species begin to expand, either through growth of residual populations within the burnt area, or through colonisation from outside, or both. Animal species often show a preference for particular stages of post-fire regeneration, with some favouring the open herb-rich early stages, and others the thicker, more complex structure that develops when fire is absent for a time. Of course, fauna habitat preferences are also influenced by vegetation type, presence or absence of particular food plants, competition from other species, and predation. Removing feral predators may allow species that would otherwise favour late successional stages, to return more rapidly (Lindenmayer *et al*. 2009).

Parma wallaby (Macropus parma) (Mark Sanders, EcoSmart Ecology).

Some species also prefer the vegetation characteristics associated with a particular frequency of fire. These different habitat preferences highlight the importance of maintaining a mosaic (i.e. variation) of post-fire ages and stages, as well as a range of fire frequencies. Some species routinely move across boundaries in the mosaic. For example the parma wallaby (*Macropus parma*) shelters in thick shrubby sclerophyll forest during the day, coming out at night to feed in open grassy patches (NSW Office of Environment and Heritage 2012).

Brown antechinus (Antechinus stuartii) (Mark Sanders, EcoSmart Ecology).

Fire and small mammals

Tasker and Dickman (2004) studied the influence of fire in wet sclerophyll forests of northern NSW, comparing small mammal abundance in sites that were frequently burnt (around 2 - 5 year intervals) as part of grazing leases, and sites that had not had a fire for over 15 years. Bush rats (*Rattus fuscipes*) were much more common on the unburnt sites, with their thick understorey of shrubs, vines and small trees. Brown antechinus also favoured these areas. However, two rare species, the New Holland mouse (*Pseudomys novaehollandiae*) and the Hastings River mouse (*Pseudomys oralis*) were only found on the frequently burnt sites, which had a diverse understorey of grasses and herbs. Swamp rats (*Rattus lutreolus*) were also more numerous on burnt sites.

Hastings River mouse (Pseudomys oralis), Gradys Creek, in the Border Ranges (K. Taylor).

New Holland mouse (Pseudomys novaehollandiae), Bostocks Waterholes, Pillar Valley, in the hinterland of Yuraygir National Park (M. Graham).

Longhorned beetle (Family Cerambycidae) (C. Welden).

Dark-flecked garden sunskink (Lampropholis delicata), captured in Bauple (D. Virkki).

Fire, ants and beetles

For many decades, researchers and foresters have maintained a fire experiment in spotted gum (*Corymbia citriodora*) dominated dry sclerophyll forest at Bauple, north of Gympie, Queensland (Henry 1961; Guinto *et al*. 1999; Lewis and Debuse 2012). Three different fire treatments are maintained: burning every year; burning approximately every three years; and no burning – though a wildfire burnt through part of the unburnt patch in 2006, effectively creating a fourth treatment.

Research into ants in the Bauple plots identified a marked preference for the burnt areas, which have an open understorey of kangaroo grass. While many ant species occurred in more than one treatment, 16 taxa were only found in the annually burnt area, with nine and three species exclusive to the three-year and unburnt treatments respectively (Vanderwoude *et al*. 1997). More recently, research into longhorned beetles at this same site found that they too were more abundant in the two frequently burnt treatments (Eliott 2015). This finding was mostly driven by one species, *Bethelium tillides*. However, another species, the wattle longhorn (*B. signiferum*), favoured the area where the wildfire had occurred nine years previously, probably because it contained lots of regenerating black wattle (*Acacia leiocalyx*). Furthermore, longhorned beetles were found in higher densities in frequently burnt areas with an open understory. This may be associated with the ease of flying between food sources. Beetle abundance was positively related to the volume of coarse woody debris and to healthy tree canopies (Eliott *et al*. 2019). It is therefore likely that longhorned beetles are influenced by historical fire regimes, which suggests that changes to fire regimes may impact arthropod populations in general, with possible impacts on ecosystem processes (Eliott *et al*. 2019).

Male rainbow skink (Carlia pectoralis) showingoff breeding colours (D. Virkki).

Fire frequency and reptiles

A different story emerged when Virkki (2014) surveyed reptiles across the Bauple treatments, together with several other nearby sites. Overall, reptiles were more abundant where time since fire was longer, and fire frequency was lower. The dark-flecked garden sunskink (*Lampropholis delicata*) exemplified this finding. This species was common in the long unburnt area at Bauple and in other sites that hadn't burnt for about a decade. However, the open litter rainbow skink (*Carlia pectoralis*) bucked the general trend for reptiles, preferring the annually burnt patch. Earlier reptile research at Bauple (Hannah *et al*. 1998) had similar findings. Thus, each of the Bauple treatment areas is providing valuable habitat, and together they support a wider range of fauna species than any one treatment alone.

Fire and heathland frogs

Coastal heath vegetation in SEQ provides habitat for three species of 'acid' frogs (frogs able to breed in the low pH conditions of wallum wetlands). In a two-part study, Lowe *et al*. (2013) first monitored populations of these frogs after a wildfire near Mooloolaba on the Sunshine Coast. Adult frogs continued to live in the burnt wetlands, which were still wet after the fire. A dry spell followed across the region, but when this broke, tadpoles rapidly appeared in the burnt area, leading the authors to conclude that all three species can 'stand the heat' of at least a moderately intense fire. Across 16 sites, with a range of post-fire ages, two species, including the wallum sedge frog (*Litoria olongburensis*), were more abundant in sites that had not burnt for some time, while the wallum rocket frog (*Litoria freycineti*) showed a marked preference for recently burnt sites.

Wallum rocket frog (Litoria freycineti) in recently burnt habitat, Sunshine Coast (K. Lowe).

Time since fire and birds

McFarland (1988) surveyed birds in coastal heathlands at Cooloola, Queensland, across a range of post-fire ages from 0 to 11 years. In the first couple of years after fire, grasstree flowering attracted lorikeets and honeyeaters, along with brown quail[3] (*Coturnix ypsilophora*) and Australasian pipits[3] (*Anthus novaeseelandiae*), which fed on the abundant grass seeds available in dry open areas. Heath structure developed rapidly, with cover, density and height reaching a peak or plateau by six years post fire. Between three and eight years post fire, these thicker heaths attracted brush bronzewings (*Phaps elegans*) and southern emu-wrens (*Stipiturus malachurus*), which could now find both nest sites and food. Yet another suite of birds, including white-cheeked honeyeaters (*Phylidonyris nigra*) and yellow-tailed black cockatoos (*Calyptorhynchus funereus*), were most abundant in older heath (i.e. long unburnt) – these species used mature hakea bushes for nesting and feeding respectively.

Rainbow lorikeet (Trichoglossus haemotodus) (Mark Sanders, EcoSmart Ecology).

Yellow-tailed black cockatoo (Calyptorhynchus lathami) (Mark Sanders, EcoSmart Ecology).

[3] Two of the bird species in this example have had a scientific name change since McFarland's study: the brown quail, and the pipit, (www.birdlife.org.au/bird-profile/australasian-pipit). The pipit has also had a common name change.

Spring full of silt after fire, Kilcoy Queensland, 2019 (B. Lord).

Fire and soil

Fire and soil properties

Soil properties can be considerably affected by fire. Fire impacts soil organic matter, nutrient availability, soil characteristics (such as pH and density) and soil biota. These impacts are influenced by the topography, fuel loads, soil moisture and fire intensity and duration (Verma and Jayakumar 2012). This in turn influences the uptake of nutrients by plants and therefore the ability of plants to regenerate and reproduce after fire.

Fires cause a temporary shift in the biogeochemical structure of soils, with a possible rejuvenating effect through the release of phosphorus, although this is dependent on vegetation and soil type (Butler *et al*. 2017; Butler *et al*. 2018a). Long-term fire regimes can affect leaf litter and soil chemistry, with research showing high frequency fire can severely deplete soil nitrogen, relative to phosphorus (Butler *et al*. 2018a; Butler *et al*. 2018b). Changes to leaf litter chemistry can affect litter decomposition processes, with potential consequences for ecosystem carbon storage and fuel characteristics (Butler *et al.* 2017; Butler *et al*. 2019a). Moreover, long-term fire regimes can affect the way soil carbon dioxide emissions respond to rising temperatures (Butler *et al*. 2019b), and this warrants consideration when planning fire regimes under a warming climate.

Fire and soil erosion

Fires can increase hillslope and watershed scale runoff, and sediment yield (Larsen *et al*. 2009). The potential for soil erosion to increase post fire is due to a loss of surface organic material and humus. As a result, the soil is not protected from rain drop splash and water holding capacity is affected (Russell-Smith *et al*. 2006). Other soil changes following fire can be the removal and partial oxidisation and or mineralisation of the soil organic matter (Bradstock *et al*. 2012; Liu *et al*. 2013). Fire can create or destroy soil water repellency, which has implications for soil infiltration, runoff, erosion (Cawson *et al*. 2016) and soil total carbon (Heath *et al*. 2015). Post-fire erosion is likely to be greatest where fire has been severe (Fernández and Vega 2016), where slopes are steep and where heavy rain occurs soon after fire.

Fire and microorganisms: fungi

Soil microorganisms such as fungi, plant roots, microbes, and soil animals, play a critical role in breaking down organic matter and releasing the decomposed materials to the soil and atmosphere (York *et al*. 2012). Fungi are essential components of all ecosystems, acting as symbiotic partners, decomposers and nutrient cyclers, and as a source of food for vertebrates and invertebrates. However, there is relatively little research on the response of fungal communities to fire (Bastias *et al*. 2006).

Fire changes the environment in which soil microorganisms live by affecting soil structure, nutrient availability, organic and inorganic substrates and other biotic components with which fungi interact, particularly mycophagous animals (animals that consume fungi as part of their diet; McMullan-Fisher *et al*. 2011). Whilst there is usually an immediate loss of soil microorganisms following a fire (Liu *et al*. 2013), research has found that fungi, bacteria and soil fauna do recover quickly following lower intensity fire (Bradstock *et al*. 2012). Their survival is influenced by the amount of leaf litter present both during a fire and post fire, and the conditions following a fire (Gonzáleź-Pérez *et al*. 2004). The responses of fungi to fire are highly variable – current recommendations are to provide a mosaic of differing fire frequencies and intensities across the landscape to promote a diversity of fungi species (McMullan-Fisher *et al*. 2011).

Cool Burn, Bunya Peoples' Aboriginal Corporation cultural fire workshop, Bunya Mountains, 2017 (D. Currie).

Dacryopinax spathularia, Mt Mellum, Sunshine Coast Hinterland, Queensland, a couple of weeks post fire, 2018 (N. Clancy).

Reference list

Please visit our website www.fireandbiodiversity.org.au or contact us for the full list of references.

Post-fire recovery of grasstrees and Christmas bells on the Sunshine Coast (G. Conroy, 2012).

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About the Queensland Fire and Biodiversity Consortium

Established in 1998, the Queensland Fire and Biodiversity Consortium is a network of land managers and stakeholders committed to improving fire and biodiversity management, supporting applied fire research, facilitating partnerships, and building land manager and landholder capacity.

The Queensland Fire and Biodiversity Consortium offers a range of resources and services, including fire management planning workshops, training and practical information. For more information, visit **www.fireandbiodiversity.org.au**.

The Queensland Fire and Biodiversity Consortium is a program of Healthy Land & Water. Healthy Land and Water is the **peak environmental group** for South East Queensland. For over 20 years it has been dedicated to investing in and leading initiatives to **build the prosperity, liveability, and sustainability of our 'future region'**. Working in partnership with Traditional Owners, government, private industry, utilities and the community, Healthy Land and Water delivers innovative and science-based solutions to challenges affecting the environment. The combination of scientific expertise and on-ground management works to deliver Healthy Land and Water's mission to **lead and connect through science and actions that will preserve and enhance our natural assets and support resilient regions long into the future**. For more information, please visit **www.hlw.org.au**, email info@hlw.org.au, or telephone (07) 3177 9100.

We acknowledge that the place we now live in has been nurtured by Australia's First Peoples for tens of thousands of years. We believe the spiritual, cultural and physical consciousness gained through this custodianship is vital to maintaining the future of our region.

The Queensland Fire and Biodiversity Consortium gratefully acknowledges the following partners:

Brisbane City – Dedicated to a better Brisbane; City of Gold Coast; Gympie Regional Council; City of Ipswich; City of Logan; Moreton Bay Regional Council; Noosa Council; Redland City Council; Scenic Rim Regional Council; Somerset Regional Council; South Burnett Regional Council; Sunshine Coast Council; Toowoomba Region; Powerlink Queensland; Rural Fire Service Queensland; Queensland Government; Seqwater

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