Long-unburnt habitat is critical for the conservation of threatened vertebrates across Australia

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Abstract
Context Increases in fire frequency, intensity and extent are occurring globally. Relative to historical, Indigenous managed conditions, contemporary landscapes are often characterised by younger age classes of vegetation and a much smaller representation of long-unburnt habitat.

Objectives We argue that, to conserve many threatened vertebrate species in Australia, landscape management should emphasise the protection of existing long-unburnt patches from fire, as well as facilitate the recruitment of additional long-unburnt habitat, while maintaining historically relevant age distributions of more recently burned patches.

Methods We use a range of case studies and ecosystem types to illustrate three lines of evidence: (1) that many threatened vertebrate species depend on mid-to late-successional ecosystem attributes; (2) disturbance to long-unburnt habitat tends to increase risk of future disturbance and ecosystem collapse; and (3) contemporary landscapes exhibit a range of characteristics that differ to historical conditions and require context-specific management.

Conclusions It is crucial that we adequately consider the implications of altered contemporary landscapes for management activities that aim to conserve threatened vertebrates. Contemporary landscapes often lack a range of critical structural and compositional components typical of late-successional habitat that are required for the persistence of threatened vertebrates. We need to shift towards strategic, objective-driven approaches that identify and protect long-unburnt habitats and promote their recruitment to enable recovery of many declining and threatened species.

Keywords Population decline · Disturbance · Fire regime · Habitat structure · Novel ecosystems · Threatened species
Introduction

Ecological disturbance regimes are being disrupted worldwide, with changing fire regimes a growing issue (Webster et al. 2005; Seidl et al. 2017; Bowman et al. 2020). Human induced changes to the frequency, intensity and extent of fires are currently causing widespread impacts on biodiversity globally (Giam 2017; Kleinman et al. 2019; Kelly et al. 2020). In many ecosystems, increasingly frequent wildfires are symptomatic of anthropogenic climate change, with weather-induced pyrogeographic shifts occurring globally (Duane et al. 2021). Since 1979, there has been a global increase of 19% in mean fire weather season length, and a doubling of the percentage of global vegetated area experiencing long fire weather seasons (Jolly et al. 2015). In California, the increasing extent of summer fires between 1972 and 2018 has led to a 405% increase in annual burnt area (Williams et al. 2019). Along with increasing temperatures and increasingly severe fire weather, wildfires are predicted to become both more frequent and extreme (Bowman et al. 2020), with such changes compromising the structural and functional attributes of vulnerable ecosystems (Westerling et al. 2011). While the specific type, frequency, intensity, and extent of fire events varies substantially between different ecosystem types and vegetation communities, relative increase in these factors is a common theme worldwide (Bowman et al. 2020). These changes can be considered as a shift in the frequency distribution of fire regime attribute values across the landscape (Fig. 1), which has flow-on effects to structural and functional characteristics at a landscape scale.

Globally, at least 4400 IUCN-listed threatened species are being adversely affected by contemporary fire regimes (Kelly et al. 2020; i.e. changes to the frequency, timing, intensity and extent of fire events; Gill 1975; McCarthy et al. 1999). The vast majority of these species are being adversely affected by contemporary fire regimes (Kelly et al. 2020). The specific type, frequency, intensity, and extent of fire events varies substantially between different ecosystem types and vegetation communities, relative increase in these factors is a common theme worldwide (Bowman et al. 2020). These changes can be considered as a shift in the frequency distribution of fire regime attribute values across the landscape (Fig. 1), which has flow-on effects to structural and functional characteristics at a landscape scale.

Animal species exhibit a diversity of fire-related habitat requirements, influenced by different aspects of fire history such as time since fire, long-term mean inter-fire interval, and fire seasonality. While some species require habitat conditions generated by frequent or recent fire (Swanson et al. 2011), we present the case that those requiring long-unburnt or rarely-burnt habitat are broadly susceptible to a common directionality of intensifying fire regimes. We use a range of case studies and ecosystem types from Australia to illustrate three main points: (1) many threatened vertebrates depend on mid- to late-successional ecosystem attributes; (2) disturbance to long-unburnt habitat tends to induce feedback loops that promote future disturbance and increase risk of ecosystem collapse (see Bergstrom et al. 2021); and (3) contemporary landscapes exhibit a range of characteristics that differ to historical conditions and require context-specific management, including the protection and recruitment of long-unburnt habitat.

The decline of long-unburnt habitat

We contend that contemporary Australian landscapes tend to be dominated by younger age classes of vegetation, and have a much smaller representation of long-unburnt areas, compared to historical conditions. We define historical conditions as those existing prior to European colonisation (starting in 1788), after which dispossession of land from Traditional Owners and subsequent environmental changes became increasingly influential. Unfortunately, data on the historical age-class distribution of vegetation

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communities is extremely sparse, due to the difficulty in obtaining quantitative data from up to thousands of years in the past. There are, however, a small number of examples that reflect this broader pattern or occur in regions that were being traditionally managed by Indigenous Australians well into the twentieth century. For example, only about 1% of mountain ash forest in south-eastern Australia remains in a mature or old-growth age category (> 120–150 years), compared to historical (i.e. before 1788) levels of 30–60% (Lindenmayer 2009; Lindenmayer et al. 2012). In north-western Australia, on the traditional land of the Karajarri people (where traditional lifestyles were being lived by some families up until the 1960s), the proportion of desert shrub and grassland vegetation with a post-fire age of at least 4 years has been reduced from 90 to 30% since the 1940s (Blackwood et al. 2022). Another study found that the proportion of semi-arid shrublands with a post-fire age of at least 50 years was reduced from about 63% in 1998 to 34% after 2005, due to a series of large fires in 1999–2004, although in that case it is unclear where this change sits relative to historical fluctuations (Doherty et al. 2017).

Fig. 1 Conceptual diagram showing a shift in the frequency distribution of historical and contemporary fire regime attributes across a hypothetical savanna landscape. Historical landscapes contained more regrowth of overstorey trees and complex structural attributes, such as tree cavities, coarse woody debris, and diverse shrub/midstorey layers. Contemporary landscapes with high fire frequencies/intensities exhibit much lower structural complexity and mid-storey diversity, with low levels of overstorey regeneration. Point attributes of the fire regime may include factors such as frequency, intensity, timing and seasonality, while spatial attributes often include measurements of extent, patchiness and/or shape. Here, we represent frequency and intensity as a mean value within each pixel, and these values do not necessarily covary. For example, a single pixel could display high frequency fires but have low intensity fires or vice versa. Spatial properties are represented by the arrangement and connectivity of pixels, broadly reflecting patterns of spatial heterogeneity across the landscape.
(Clarke et al. 2010), and a range of spinifex (*Triodia* spp.) dominated communities (Box 1; Fig. 2).

Contemporary long-unburnt patches often consist of small and isolated areas nested within a broader, more recently disturbed matrix (Camp et al. 1997). These patches can even be deterministic in origin, occurring in parts of the landscape that are naturally less prone to disturbance events (Robinson et al. 2013), whether due to isolation from anthropogenic influence or subtly different abiotic characteristics (e.g. soil moisture availability, topography). However, as is the case for many forms of chronic environmental degradation, shifting baselines make the identification of changes to age-class distributions of vegetation communities very difficult to observe and manage accordingly (Soga and Gaston 2018). Further, increasingly acute impacts resulting from climate change are likely compounding the issue, highlighted by the extreme 2019–2020 fire season. Recent analysis by an expert panel suggested that at least 28 ecological communities had > 50% of their mapped area affected by this single fire season (Keith et al. 2021).

Contributing factors to the decline in long-unburnt habitat include disruption of Indigenous burning regimes (Blackwood et al. 2022), extreme fire weather conditions due to climate change (de Groot et al. 2013; van Oldenborgh et al. 2020), increased use of prescribed burning (Penman et al. 2011), and interaction with other threatening processes such as logging (Lindenmayer et al. 2009, 2021a, b) and weed invasion (Setterfield et al. 2010). Evidence for feedbacks is emerging, whereby the loss of old growth vegetation or ‘natural firebreaks’—such as moist rainforest vegetation in topographic drainage lines—may increase the severity and/or connectivity of fire in the landscape (Lindenmayer et al. 2011a, b).

As the spatial distribution and extent of long-unburnt habitat declines, threats to species persistence can manifest in several ways. In the case of increasingly frequent fire, threats occur because: (1) the life histories of some fire-sensitive species require long inter-fire intervals due to slow population growth or age at maturity (Bowman et al. 2014; Enright et al. 2015; von Takach Dukai et al. 2018); (2) critical habitat features for many species are associated with time since fire (Gibbons et al. 2000; Nimmo et al. 2012; Croft et al. 2016; Doherty et al. 2017); and (3) important habitat features can be associated with inter-fire interval (e.g. fire in long-unburnt habitat generates post-fire habitat structures, such as large dead standing trees, that do not occur when inter-fire intervals are short; Pereoglou et al. 2011; O’Loughlin et al. 2020).

![Fig. 2](image)

**Fig. 2** Old-growth spinifex and associated vegetation communities support an array of rare or threatened species, such as a the Arnhem phasmid gecko and b white-throated grasswren. Grasswrens (*Amytornis* spp.) nest in large spinifex hummocks, which provide good protection from predators. Photos by C Jolly (a) and B von Takach (b) (Box 1)
Hummock-forming spinifex grasses (Triodia spp.) are a critically important habitat component in a diverse array of Australian ecosystems, including mallee communities of southern semi-arid and arid zones, sandstone ridges and escarpments of northern Australia, and spinifex grasslands of the inland deserts. Spinifex-dominated communities represent approximately 20% of the Australian continent, and a multitude of reptile and bird species have adapted to life with spinifex (Melville and Schulte 2001; Sass et al. 2011; Nimmo et al. 2013; Harrington and Murphy 2016). Structural features such as dense mats of dead material and large protective rings of spines provide protection from predators, suitable microclimates and/or critical breeding habitat for many taxa, including rare or threatened species (Masters 1996; Moore et al. 2015; Stoetzel et al. 2020; Bell et al. 2021), such as the Arnhem phasmid gecko (Strophurus horneri) and white-throated grasswren (Amytornis woodwardi; Fig. 2).

Patches of long-unburnt spinifex hummocks also provide crucial diurnal roost and nesting sites for the extremely cryptic and endangered night parrot (Pezoporus occidentalis) (Murphy et al. 2017a, b). Unfortunately, contemporary fire regimes in many areas are preventing growth and development of requisite structural features, which can take decades to fully develop, resulting in the decline of habitat specialist species such as the red-lored whistler (Pachycephala rufogularis), black-eared miner (Manorina melanotis), white-bellied whipbird (Psophodes leucogaster) and emu-wrens (Stipiturus spp.) (Harrington et al. 2011; DELWP 2016; Connell et al. 2017). The endangered mallee emu-wren (S. mallee) was extirpated from the state of South Australia due to an inappropriate fire regime, and is now the subject of a resource-intensive reintroduction and monitoring program (Brown 2014; Verdon et al. 2021; Mitchell et al. 2021).

**Box 1: Long-unburnt spinifex communities are critical habitat**

The value of mid- to late-successional ecosystem attributes

Many threatened species depend on one or more critical habitat components, such as tree cavities, coarse woody debris, and large grass hummocks. These critical habitat features are often most abundant in long-unburnt habitats. For example, in south-western Australia, four threatened bird species (the western ground parrot Pezoporus flaviventris, western bristlebird Dasynornis longirostris, noisy scrub-bird Atrichornis clamosus, and black-throated whipbird Psophodes nigrogularis) are restricted to scattered remaining patches of vegetation communities dominated by heaths, sedges, and low eucalypts (Smith 1985). These birds rely on relatively moderate (5–10 years post-fire) to long (10+) intervals between fire events for population persistence (Meredith et al. 1984; Smith 1991, 1996; Burbidge et al. 2007), with more frequent fire causing the loss of functional and structural attributes that individuals rely on for food resources and protection from predators (Burbidge 2003).

Tree cavities are a commonly used resource by vertebrates worldwide, with 18.1% of all bird species in the world using cavities for nesting, and 13.2% of those species listed as threatened under IUCN Red List criteria (van der Hoek et al. 2017). In Australia, tree cavities are used by over 300 vertebrate species (Gibbons and Lindenmayer 2002), and are required for breeding by many threatened bird species, such as large forest owls (Tyto and Ninox spp.), the Gouldian finch (Erythrura gouldiae), and swift parrot (Lathamus discolor). Cavities are also used for denning and shelter by threatened mammals and reptiles, such as the arboreal Leadbeater’s possum (Gymnobelidus leadbeateri) and yellow-bellied glider (Petaurus australis), and semi-arboreal broad-headed snake (Hoploccephalus bungaroides). Cavity formation in Australia is typically initiated by (1) natural death and decay of limbs or trunks (Gibbons and Lindenmayer 2002), (2) disturbance events such as cyclones or fires (Woolley et al. 2018), and (3) piping of trunks or limbs by termites (Woolley et al. 2018; Penton et al. 2020). There can also be interactions between...
these factors (e.g. with mechanical damage from fires allowing termite ingress into trees). In some southern Australian forests, cavities that are suitable for vertebrates often require 120 to 180 years of tree growth to develop, and sometimes longer (Wormington and Lamb 1999; Gibbons et al. 2000; Gibbons and Lindenmayer 2002). In forests dominated by tree species that are killed by fire, this means long periods without fire may be necessary for hollows to form. In forests dominated by trees that regenerate following fire, the relative abundance of hollows may be determined more by the age of the trees and past land use (e.g. logging).

Unfortunately, increasing disturbance frequency and intensity, particularly from logging and wildfires (Lindenmayer et al. 1997), and sometimes even low intensity prescription burns (Parnaby et al. 2010), is rapidly reducing the abundance of cavity-bearing trees across much of Australia’s southern forested landscapes. These factors have resulted in several Australian jurisdictions listing “the loss of hollow-bearing trees” as a key threatening process (Parnaby et al. 2010). In the frequently burnt tropical savanna of northern Australia, trees capable of supporting large (> 30 cm entrance diameter) cavities are scarce (Woolley et al. 2018; Penton et al. 2020), and it is well-established that high-intensity fires cause high rates of mortality in both the smallest and largest trees (Lehmann et al. 2009; Prior et al. 2009; Williams et al. 1999). Importantly, ecologically based fire management is often undertaken based on thresholds of lower and upper intervals of fire tolerance for a subset of plant species in an area, and fails to include the substantially longer inter-fire intervals required for the formation and preservation of habitat attributes such as tree cavities and coarse woody debris (Manning et al. 2007; Haslem et al. 2011; Croft et al. 2016).

This leads to the critically important distinction between species that persist in disturbed or early successional habitats and species that persist under regimes of high frequency disturbance (i.e. species for which the inter-fire interval matters; O’Loughlin et al. 2020). For example, the critically endangered Leadbeater’s possum can be relatively abundant in recently disturbed (e.g. 15–50 years post-fire) wet forest communities, but only if older cavity-bearing trees suitable for nesting and denning are present (Smith and Lindenmayer 1992). When very young forest is burnt, such legacy structures are absent from the regrowth vegetation and Leadbeater’s possum is unlikely to occur (Todd et al. 2016; Taylor et al. 2017; Nitschke et al. 2020). Similarly, the threatened eastern chestnut mouse (Pseudomys gracilicaudatus) tends to occupy early- to mid-successional phases of densely shrubby or heathland habitats (Fox 1982; Pereoglu et al. 2011). This species relies on collapsed dead shrubs for diurnal refuge sites, which are created by recent fire but are also less abundant in sites where younger heathland was burnt (Pereoglu et al. 2011, 2016).

When structural components of mid- to late-successional vegetation are present, the risk of predation by native (e.g. dingo Canis familiaris) and introduced (e.g. cat Felis catus and fox Vulpes vulpes) predators may decline due to differences between species in habitat preferences/associations and success of predation attempts (Dickman 1996; McGregor et al. 2015). The use of structural habitat features to reduce the risk of predation has been demonstrated to be important for a range of taxa (Janssen et al. 2007), including small mammals (Jacob and Brown 2000; Stokes et al. 2004) and birds (Chalfoun and Martin 2009). Recent wildfires markedly reduce habitat structural complexity across the landscape, potentially increasing vulnerability of threatened vertebrates to predation pressure. Indeed, research suggests some predators may actively seek out recently burnt areas because of the increased predation opportunities they offer (McGregor et al. 2014, 2015). Although many species may be adapted to survive the initial fire event (Nimmo et al. 2021; Jolly et al. 2022), post-fire survival can be significantly reduced by increased exposure to predators (Leahy et al. 2016; Wintle et al. 2020) and reductions in resource availability (Williams et al. 2010; Lindenmayer et al. 2011b).

**Frequent disturbance increases risk of ecosystem collapse**

In many ecosystems, disturbance events appear to promote conditions that increase the probability of subsequent disturbance. For example, recently burnt rainforest and moist forests are not only more prone to ignition (Lindenmayer et al. 2009), but are also more likely to experience high-severity fires than undisturbed patches (Zylstra 2018). Similarly, high severity fires increase the probability of future high...
severity fires in dry eucalypt forests (Barker and Price 2018). Such changes to the frequency or intensity of disturbance causes ecosystems to decline in spatial extent, lose keystone species, exhibit signals of environmental degradation, and eventually lose ecosystem services and functions (Keith et al. 2013; Bland et al. 2017, 2018; Sato and Lindenmayer 2018). In some instances, these positive feedback loops can modify the structural attributes of ecosystems to such an extent that they shift into a novel or alternate ecosystem state (Johnstone et al. 2010; Lindenmayer et al. 2011a, b; Young and Clements 2009). Indeed, across Australia, changes to fire regimes have already partially led to this type of ecosystem collapse in at least 12 major Australian ecosystem types, including a range of arid zone, cool temperate, high elevation, and Mediterranean communities (Bergstrom et al. 2021). While abrupt shifts in fire regimes sometimes result in highly visible sudden changes in ecosystem structures (Lindenmayer et al. 2011a, b), it is possible (in the absence of long-term monitoring programs) that more subtle changes are going undocumented in other communities due to long generation times of keystone species, and shifting baseline syndrome (Pauly 1995).

A prime example of the process by which disturbed habitats become more prone to disturbance is currently occurring in the vast areas of northern Australian savannas and warrants further discussion. Tropical savanna dominates northern Australia, representing approximately one quarter of the continent’s landmass. Tropical savannas are the most fire-prone biome on the planet (Andersen et al. 2012), with many areas of northern Australia burning annually due to a combination of natural ignitions and anthropogenic influences (Russell-Smith and Yates 2007). While fire is integral to maintaining this system (Bowman 2000; Bond and Parr 2010; Andersen 2021), the frequency, intensity and extent of wildfires has changed substantially over the past 200 years, resulting in landscapes dominated by highly simplified vegetation structure and the loss of structural characteristics that are relied upon by a diverse array of vertebrate fauna (Bowman et al. 2004; Russell-Smith et al. 2012; Woinarski and Legge 2013; von Takach et al. 2020).

The broadscale loss of spatial heterogeneity in vegetation structure across savanna landscapes leads to the promotion of species that are early-successional specialists or otherwise tolerant of frequent disturbance, particularly for birds and mammals (Andersen 2021). Further, introduced gamba grass (Andropogon gayanus) is rapidly spreading through Australia’s tropical savanna ecosystems, due to its preference for high frequency and high severity fires (Setterfield et al. 2010). With its large size and high biomass, the presence of gamba grass at a site promotes high severity fires, which contributes to loss of tree cover, conversion of savanna woodland to open grassland, and alters litter decomposition and nitrogen fluxes (Rossiter et al. 2003; Rossiter-Rachor et al. 2017). Together, these factors result in a strong feedback loop and a ‘trapped’ landscape. Such trapped landscapes are extremely difficult to convert back to historical conditions, often requiring costly and intensive manual or mechanical removal of weedy species and/or artificial sowing of species that were historically present (Gibson-Roy et al. 2010; Bassett et al. 2015; Sims et al. 2019). Worryingly, once an ecosystem reaches an alternative state, simply reversing the processes (e.g. increased fire frequency) that led to the change in state does not necessarily result in a reversion back to historical ecosystem structure and composition (Collins et al. 2021).

**Challenges and opportunities for contemporary landscape management**

The effects of habitat fragmentation and degradation on the persistence of plant and animal populations are well known (Andersen et al. 2004; Gerber et al. 2012; Banks and Lindenmayer 2014; Pavlova et al. 2017), with generalist and/or widespread species tending to be more able to persist in degraded or disturbance-prone environments (McKinney and Lockwood 1999; Zeeman et al. 2017; Richardson et al. 2018; Everingham et al. 2019). However, contemporary landscapes exhibit a large range of characteristics that differ to historical conditions. As discussed above, contemporary long-unburnt patches are often small and isolated areas that are nested within a more recently disturbed matrix (Camp et al. 1997; Parsons et al. 2011; Driscoll et al. 2021). In addition, many Australian ecosystems are missing a whole suite of important vertebrate ecosystem engineers that have gone locally, regionally, or globally extinct since European colonisation in 1788 (Fleming et al. 2014; Woinarski et al. 2015; Halstead et al. 2020). The regular foraging
and burrowing activities of many extirpated rodent
and marsupial species would have disturbed vast
amounts of soil across the continent, with a myriad
of ecological effects including the redistribution of
resources (Mallen-Cooper et al. 2019), modification
of plant demographics (Gordon and Letnic 2019),
and moderation of fuel loads and fire characteristics
(Hayward et al. 2016; Ryan et al. 2020). Simultane-
ously, exotic herbivores and predators have become
dominant components of these ecosystems (Freeland
1990; Dickman 1996). Lastly, novel ecosystem attrib-
utes or states are produced through the invasion and
establishment of exotic weed species that benefit from
frequent disturbance (Fisher et al. 2009). All of this
tells us that the structure and composition of the land-
scape matrix is, in many situations, vastly different to
what would have occurred historically.

There is popular support for reinstating pre-Euro-
pean Indigenous burning regimes in Australia, but
there is uncertainty about the nature of these prac-
tices and the associated landscape characteristics for
most ecosystems (Prober et al. 2016; Bardsley et al.
2019). In many cases, burning was more frequent in
the past, but the fires were smaller and often clus-
tered around travelling routes and water points (e.g.,
Bliege Bird et al. 2008; Burrows and Chapman 2018;
Blackwood et al. 2022). For example, in the Great
Western Woodlands of south-western Australia, burn-
ing by Ngadju People was common, but the locations
of fires across the landscape were very targeted rather
than ubiquitous (Prober et al. 2016). Understanding
Indigenous management techniques should be a key
priority for many Australian ecosystems, and has cul-
tural and ecological benefits (Greenwood et al. 2021).
However, the loss of long-unburnt habitat patches,
with respect to both their frequency and overall rep-
resentation within landscapes, points to the need for
active stakeholder collaboration to design appropri-
ate management plans for landscapes that are man-
ger for multiple, sometimes competing, objectives.
Recent studies have begun to quantify age-class dis-
tributions of vegetation that would benefit species of
conservation concern (Giljohann et al. 2018), high-
lighting the need for a greater extent of long-unburnt
vegetation (Davies et al. 2018; Radford et al. 2021),
and there may be opportunities to integrate other val-
ues and objectives into these tools.

It is crucial that we adequately consider the impli-
cations of novel environmental contexts when
managing landscapes for threatened vertebrates, par-
ticularly in light of how little is known about histori-
cal conditions, including Indigenous burning prac-
tices, in many locations (Connor et al. 2018; Ross
et al. 2020). The concepts of historical baselines, ref-
ereence conditions, and benchmarking are entrenched
in restoration and management practices around the
world (Parkes et al. 2003; Stoddard et al. 2006;
Jakobsson et al. 2020), so careful evaluation of the
metrics and methods used for landscape management
of biodiversity is critical (Kopf et al. 2015; Ruaro
et al. 2021). In this sense, returning highly modified
contemporary landscapes to historical management
practices may not necessarily benefit the threatened
species that require the most conservation manage-
ment (Whitehead et al. 2003). For example, the appli-
cation of a historical fire regime to a patch of long-
unburnt grassy woodland may appear to be a suitable
approach from a management perspective if it super-
icially imitates methods used by Traditional Own-
ers; however, it could also threaten the persistence of
species that depend on structural features associated
with late-successional environments, because long-
unburnt patches are now rare where they were once
common. If such a method were applied to the entire
landscape uniformly, in conjunction with adequate
weed management, feral herbivore management, and
predator management for a period of decades or cen-
turies, long-unburnt patches could be indirectly cre-
ated and maintained, but the species that depend on
such patches may have long since been extirpated.

Thus, the contemporary landscape context should be
carefully considered when aiming to protect exist-
ing long-unburnt patches, such as by reducing fire in
the surrounding matrix to increase the size and num-
ber of long-unburnt patches. This should be in addi-
tion to common current approaches that focus on
improving broad patterns of landscape heterogeneity
or pyrodiversity, with the implicit goal of increas-
ing the proportion of long-unburnt vegetation in the
landscape. This idea has recently been emphasised in
an assessment of the impacts of the 2019–2020 fire
season, which found that 36 ecological communities
require urgent protection of fire refuges from future
fires, and 42 ecological communities require urgent
protection of burnt areas from future fires (Keith et al.
2021).

The methods by which long-unburnt patches are
protected from fire and other disturbances will differ
between ecosystem types and regions. Modern fire management techniques in large landscapes may involve prescribed aerial burning, on-ground fire breaks, and an ongoing commitment to wildfire suppression. Where available, actions should consider and be informed by Traditional Owner customary knowledge and landscape management aspirations (Ansell et al. 2019). In some ecosystems, such as wet sclerophyll forests, the complete absence of disturbance events may be necessary for more than a century. In other cases, such as northern Australia, the careful application of prescribed burning over the course of one to two decades has reduced fire intensity in some regions (Murphy et al. 2015), although the loss of long-unburnt habitats is still a critical issue (Freeman et al. 2017). Managing fuel loads and protecting human lives and property is an additional consideration (Nolan et al. 2021), and we recommend that burning plans are informed by empirical tools such as multi-criteria decision analysis (Penman et al. 2020) and spatial prioritisation (Prato and Paveglio 2019). Recently, alternatives to the use of historical baselines have also been promoted, such as the recognition of “best-on-offer” reference states (Yen et al. 2019), and such alternatives may provide a more useful philosophical approach to biodiversity conservation in contemporary landscape contexts.

Broadly, we suggest that contemporary landscape management in Australia would benefit from greater emphasis on quantifying historical vegetation age-class distributions, as well as understanding the vegetation age-class distributions that benefit species of conservation concern. This is difficult due to the time scale of the broadscale habitat degradation and landscape modification that have occurred in many Australian ecosystems—a problem that replicating through space (e.g. via a chronosequence) can only partially address (Giljohann et al. 2018; Gosper et al. 2019). However, such information would help to address uncertainty around the extent to which contemporary vegetation age-class distributions truly represent a long-term downward trajectory. Ultimately, if we are to conserve habitat features critical to the persistence and recovery of declining and threatened species, ad hoc species conservation management (Scheele et al. 2018), driven by a lack of funding and a lack of science-based decision-making (Russell-Smith et al. 2015), needs to shift towards strategic, objective-driven approaches. Long-unburnt habitat is critical for the conservation of threatened vertebrates across Australia—we would be wise to ensure that the future of fire management in Australia includes strategies to actively protect and recruit long-unburnt habitats across this fire-prone continent.

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