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Conserving large old trees as small natural features

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ABSTRACT

In many ecosystems globally, large old trees occur as single, spatially isolated individual trees or as small groups of scattered trees and can therefore be considered to be small natural features. Despite being constrained spatially, individual large old trees and small stands of such trees nevertheless play numerous critical ecological roles (e.g. in carbon storage and provision of wildlife habitat). The protection and management of large old trees as small natural features is essential to maintain these roles and will often require targeted fine-scale conservation strategies. Such strategies can include bans on cutting trees above a certain size, micro-fencing to control threats associated with livestock grazing, and buffers comprised of other vegetation to limit the impacts of fire and chemical sprays. Effective conservation to mitigate the effects of factors threatening large old trees will often demand ecosystem-specific responses. This is because the drivers of loss will often manifest in ecosystem-specific ways. Three general principles will likely apply in almost all cases: (1) Protect existing individual large old trees; (2) Reduce rates of adult mortality. This is because adult mortality is a key part of the life cycle of large old trees; increased adult mortality can lead to population crashes; and (3) Ensure there are sufficient recruits of trees of varying ages to replace existing large old trees as they eventually die.

1. Introduction

Small natural features (SNFs) are parts of ecosystems that make a disproportionately substantial contribution to ecological processes and/or biodiversity relative to their small size (Hunter, 2017–in this issue). Large old trees qualify as SNFs in many ecosystems worldwide. These include wood production forests subject to extensive or intensive human modification such as repeated logging and where large old trees can be uncommon or even rare and are often confined to relatively small areas (Linder and Östlund, 1998) (Fig. 1). Similarly, large old trees are SNFs in many non-forested ecosystems such as savannas, deserts, and heavily disturbed agricultural and urban environments in which large old trees can occur as small groups of scattered trees (Manning et al., 2006) or single isolated trees (Carpaneto et al., 2010; Moga et al., 2016) (Fig. 2).

Although large old trees can be spatially constrained and limited in abundance in many ecosystems, they can nevertheless play numerous ecological roles. Moreover, their protection can demand targeted fine-scale conservation strategies, often at the individual tree level. The primary focus of this paper is on large old trees as SNFs with a particular emphasis on conservation strategies designed to protect existing individual large old trees, maintain the array of roles played by these trees, and recruit new cohorts of trees to avoid discontinuities in abundance. First, some of the ecological roles of large old trees are outlined to provide ecological context to discussions of fine-scale conservation strategies. This is followed by a discussion of some of the many factors threatening populations of large old trees. The final sections of the paper outline ways to conserve individual large old trees and small stands of such trees with an emphasis on the management of large old trees as small natural features.

2. Key ecological roles of large old trees as small natural features

Large old trees play many ecological roles either not filled or only partially filled by small young trees, large young trees, medium sized and intermediate-aged trees, or small old trees. These include roles in ecosystem processes such as hydrological regimes, carbon storage and nutrient cycling, micro- and meso-climatic regimes, and providing habitat for an enormous array of plant and animal species (Lindenmayer and Laurance, 2016) (Fig. 3). Some important features of large old trees such as the presence of deep and extensive root networks, large cavities, large buttresses, large lateral branches, extensive canopies, prolific flowering, and extensive seed set are not characteristic of small sized or younger aged trees (Ashton, 1975; Brokaw and Lent, 1999; Gibbons and Lindenmayer, 2002; Lindenmayer and Laurance, 2016). Thus, large old trees are truly keystone structures (sensu Tews et al., 2004) in terms of their disproportionate contribution to a wide range of ecological processes and their disproportionate value for biodiversity (Manning et al., 2006).

Large old trees can continue to have important ecological roles when they occur in small clusters of trees or as individual trees. For example,

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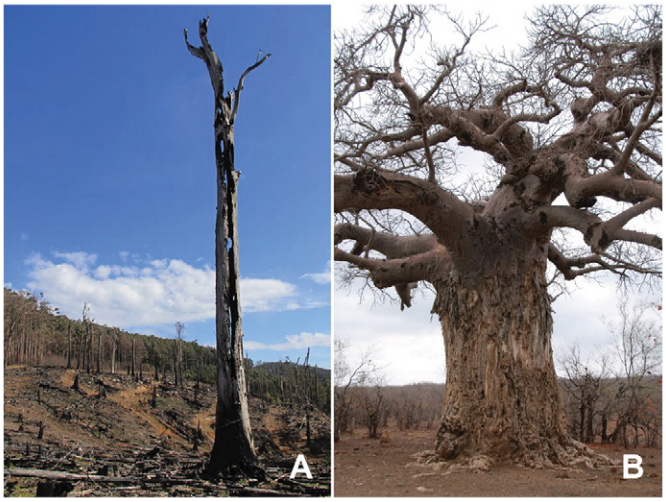

Fig. 1. Single large old trees in: A. logged Mountain Ash forests in the Central Highlands of Victoria; B. baobab tree in the tropical savannas of Kruger National Park, South Africa. Photos: (A) L. McBurney; (B) D. Lindenmayer.

they can have profound impacts on local microclimatic conditions, soil moisture and soil nutrient levels (Dean et al., 1999; Voight et al., 2015). Individual large old trees can be a small proportion of the number of stems in a given stand or area of vegetation, but nevertheless a significant contributor to the total amount of carbon stored (Slik et al., 2013). Individual large old trees can be reproductively dominant trees in an area through contributing a disproportionate numbers of germinants to new cohorts of plant recruits (Wenk and Falster, 2015). Hence, they can act as nodes of regeneration (Fischer et al., 2009). Individual large old trees and small stands of such trees can act as living "micro-hotspots" with levels of species richness and individual species abundance substantially greater than the surrounding environment. Indeed, many species of animals occur in a given area only because of the presence of large old trees (Kavanagh and Turner, 1994; Lindenmayer et al., 2014b). Several studies have shown that patterns of nesting, denning and other social behaviour by cavity-dependent animals are dramatically altered when populations of large old trees are reduced and/or

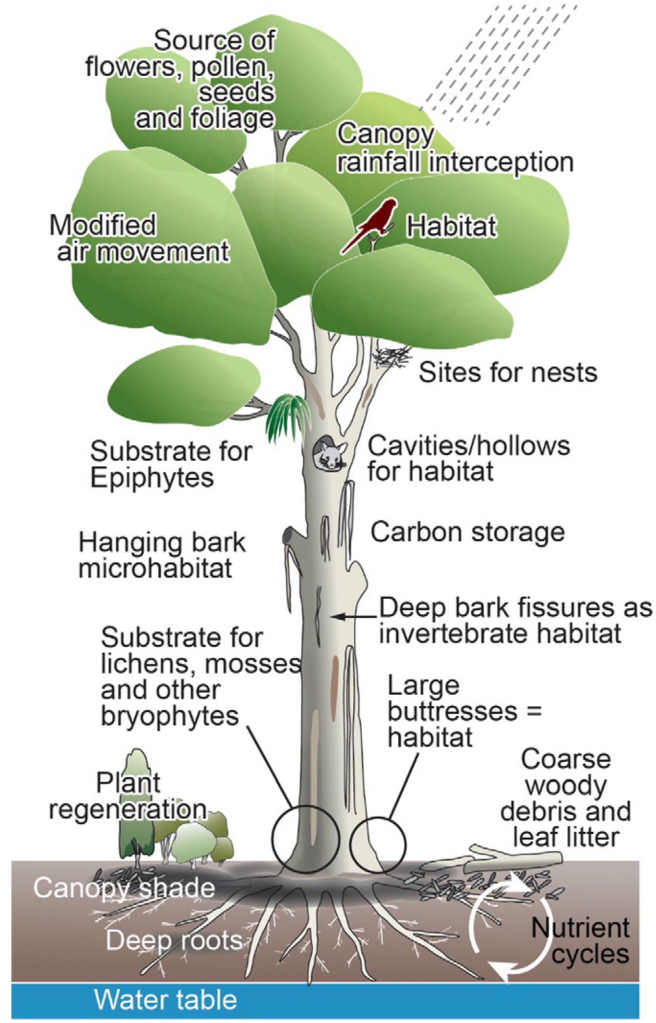

Fig. 3. Schematic representation of a subset of the array of ecological roles played by large old trees.

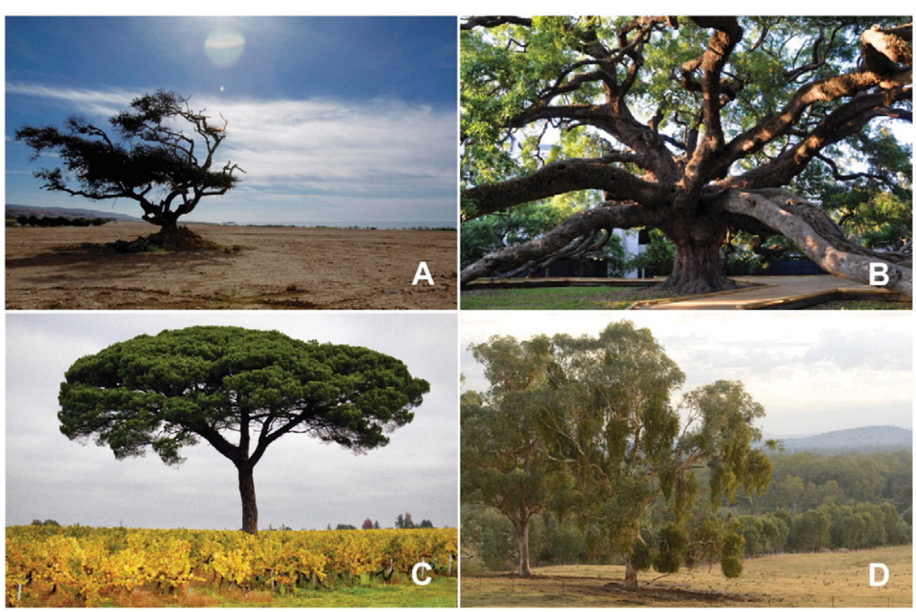

Fig. 2. Individual large old trees in non-forested environments in: A. an agricultural environment in Morocco; B. an urban streetscape in USA; C. cropping land in rural France; D. a grazing environment in Australia. Photos: (A) E Dekker (Creative Commons); (B) J Willamor (Creative Commons); (C) Ands78 (Creative Commons); (D) D Blair.

spatially constrained and occur as individual trees or small clusters of such trees (Banks et al., 2011).

3. Threats to large old trees when they are small natural features

Large old trees are susceptible to an array of ecological threats ranging from those that are global in scale such as climate change to localised ecosystem-specific threats like the impacts of a particular pathogen on a single tree species such as Kauri (*Agathis australis*) trees in the North Island of New Zealand (Landcare Research, 2014). Threats to large old trees include "natural drivers" like fire (Williams et al., 1999; Kolb et al., 2007), drought (Bennett et al., 2015) and overabundant populations of native herbivores (such as elephants (Vanak et al., 2011)). They also encompass direct human factors like logging (Gibbons et al., 2008) and land clearing (Maron and Fitzsimons, 2007; Crowther et al., 2015). Many so-called natural drivers of large old tree loss have a human origin such as the increased frequency and severity of fire and drought arising through anthropogenic climate change (Westerling et al., 2006; Anderegg et al., 2013) as well as increased abundance of native herbivores occurring through human modification of environments and populations of predators. Table 1 lists a range of threats broadly relevant to large old trees in particular environments.

The effects of some threats to large old trees can be magnified when these trees occur as small stands or individual trees. Laurance et al. (2000) showed that individual large old trees within remnant patches of rainforest are highly susceptible to windthrow within highly fragmented landscapes. In some temperate forest environments, such as those in parts of south-eastern Australia, large stands of old growth forest are exempt from logging, but small stands of old growth <5 ha in area, are poorly protected with individual large old trees often badly damaged or destroyed by timber harvesting, particularly by fires lit to promote the regeneration of cutover stands (Lindenmayer et al., 2015a). In agricultural landscapes such as those in south-eastern Australia, individual large old trees are susceptible to being cut down for firewood (Driscoll et al., 2000), and/or being cleared because they impede the movement of agricultural machinery (Maron and Fitzsimons, 2007). Other factors such as prescribed burning and wildfire can threaten scattered large old trees in agricultural environments (Crane et al., 2016). Furthermore, the area under scattered large old trees can be used as "stock camps" by cattle and sheep resulting in mechanical damage by livestock to the trunk of trees as well as high concentration of nutrients in the soil through the accumulation of dung (Lindenmayer et al., 2011a).

Many of the factors threatening individual large old trees can interact (Fig. 4). Australian agricultural landscapes provide an example where remaining large old trees in these already heavily cleared and intensively grazed and cropped landscapes are threatened by altered groundwater dynamics, raised water tables, and secondary salinity (Stirzaker et al., 2002). These dead trees are then targeted for cutting by the firewood industry, hastening the loss of tree hollows and coarse woody debris (Driscoll et al., 2000) (Fig. 4).

Table 1
Potential threats to large old trees in different broad kinds of environments. An X in a cell indicates there are documented examples where a given threat has occurred in a given environment.

Threat	Forests	Savannas	Agricultural areas	Deserts	Urban areas
Drought	X	X	X	X	X
Fire	X	X	X	X	
Windstorms	X	X	X		X
Insect attack	X		X		
Pathogens	X		X		X
Over-browsing by native herbivores	X	X		X	
Invasive plant species	X	X			X
Logging	X				
Firewood collection	X	X	X		
Land clearing	X	X	X		X
Grazing by domestic livestock		X	X	X	
Secondary salinity			X	X	
Establishment of human infrastructure	X		X		X
Spraying of fertilizer and other chemicals			X		X
Water diversion			X	X	
Climate change	X	X	X	X	X

4. Conservation activities and approaches to protect large old trees as small natural features

4.1. Activities

Several factors complicate the management of individual large old trees and small stands of such trees. First, individual large old trees can create awkward logistical and other problems creating disincentives to conserve them. For example, individual large old trees can be a threat to human safety in urban settings (Carpaneto et al., 2010), can impede the movement of farm machinery and irrigation infrastructure in agricultural landscapes (Maron and Fitzsimons, 2007), and can promote the spread of sparks in some fire-prone forest ecosystems (Crowe et al., 1984). Second, large old trees can be particularly challenging to protect from threats in the surrounding landscape such as drift from chemical spray, exposure during and after logging of adjacent stands, and the effects of pathogens dispersed by humans. Third, traditional methods of protection such as setting aside large reserves, or even meso-scale reserves, will not be possible in many commodity production areas (such as croplands), nor in urban environments. Fourth, individual large old trees and small stands of such trees occur in a wide range of natural and human-modified environments with the array of factors threatening them often manifesting in ecosystem-specific ways. Thus, the most appropriate conservation measures to mitigate these threats will likely be specific for any given ecosystem. However, three general principles are likely to apply in almost all cases: (1) protect existing individual large old trees, (2) reduce the risk of adult mortality among large old trees. This is because adult mortality is a key part of the life cycle of large old trees; increased adult mortality can lead to population crashes (Lindenmayer et al., 2012a), and (3) ensure there are sufficient recruits to replace existing large old trees as they senesce and eventually die (Manning et al., 2013).

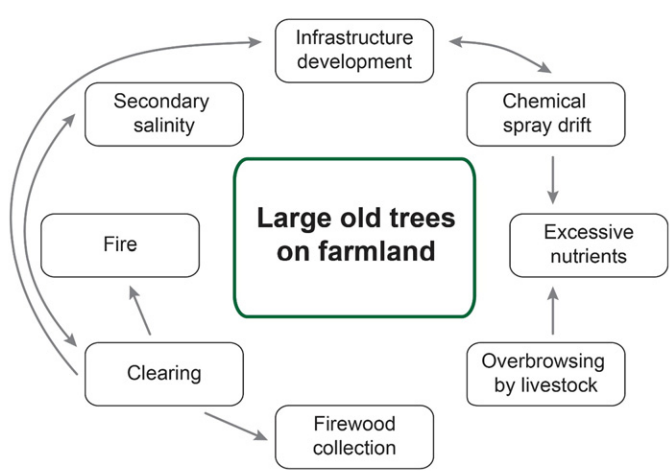

Fig. 4. Simple conceptual diagram of the potential interactions among threats to scattered large old trees in agricultural environments in eastern Australia (based on Manning et al., 2006; Lindenmayer et al., 2011a; Crane et al., 2016).

4.1.1. Educate

Many resource managers and policy makers are unaware of the need to conserve individual large old trees and small stands of large old trees. In particular, they seem unaware of the array of critical ecological roles played by large old trees (Fig. 3) and the difficulty of replicating these roles with "engineering solutions" such as the provision of nest boxes. Furthermore, management decisions are often made without considering the extensive timespans required for large old trees to develop and hence underestimate the period over which problems persist as a result of poor management decisions. An example of the problems arising from a lack of education comes from heavily cleared Australian farming landscapes in which scattered large old trees are the relictual elements (sensu McIntyre and Hobbs, 1999) of extensive past cover of temperate eucalypt woodlands. In these landscapes, many landholders are unaware that large old trees: (1) regulate water tables and can limit the risks of secondary salinity (Stirzaker et al., 2002), (2) support assemblages of invertebrates which enhance the pollination of adjacent croplands (Arthur et al., 2010), (3) act as stepping stones to facilitate the movement of wildlife (Fischer and Lindenmayer, 2002), and (4) function as nodal points to promote cost-effective natural regeneration of tree cover (Fischer et al., 2009). This lack of understanding is underscored by policies of agricultural lobby groups which actively promote the removal of large old trees on agricultural land (Victorian Farmers Federation, 2011). Substantial efforts have been made to counter this lack of awareness among farmers and other land managers including holding field workshops with private landowners, production of film clips, and the wide distribution of semi-popular books (Lindenmayer et al., 2011a).

4.1.2. Inventory

Knowledge of the size of populations of large old trees and where those trees occur is critical to guide management (Lindenmayer and Laurance, 2016; Mifsud and Harris, 2016). For example, this information is essential to determine whether populations of large old trees are increasing or decreasing (Kauppi et al., 2015), if additional management is needed (such as special protection measures; see below), and where in the landscape such management is required. Maps of the locations of large old trees can be useful in this regard, as can remote sensing (Ellis et al., 2015) and emerging technologies like Lidar to remotely and cost-effectively detect individual trees (Thomas, 2011). Citizen science also can be valuable for creating inventories of the numbers and locations of large old trees, including exceptional individuals that require special protection. As an example, in the Romanian province of Transylvania, a citizen education project enlisted the assistance of schools in >20 villages to "find the oldest trees" in wood pastures in southern Transylvania. The location, circumference, and species of trees were recorded as well as a photograph taken with information then field checked by scientists (Moga et al., 2016).

Developing inventories of populations of individual large old trees can be aided by predictive modelling of the factors influencing the likely spatial and temporal patterns of occurrence of large old trees (see Smith et al., 2012), including scattered and individual large old trees (e.g. Moga et al., 2016). However, such modelling can be constrained by the fact that large old trees of a given species may occupy only a subset of the area (and hence the environmental niche) that is potentially suitable for them. This is because enormous numbers of large old trees have been removed by humans worldwide (Crowther et al., 2015) with remaining individuals often confined to places that have escaped human land use practices.

4.1.3. Protect

Protection of existing large old trees is the single most important action in managing populations of these keystone structures. This applies in all ecosystems where large old trees occur (or should occur). The protection of large old trees will often need to include not only living stems, but also dead large old trees as they can retain key ecological roles for multiple decades after tree death such as providing habitat for wildlife (Rose et al., 2001) and storing large amounts of carbon (Keith et al., 2009). Strategies to maintain populations of large old trees also must protect potential recruit trees, some of which will eventually become large old trees (Manning et al., 2013). Protection must be long-term because of the prolonged periods (often exceeding centuries) needed for new cohorts of trees to attain an equivalent size and condition to replace existing large old trees.

Decisions about protection strategies need to be guided by the abundance of large old trees elsewhere in a given environment, trends in population dynamics, and the roles played by large old trees (and the ability of smaller and younger trees to assume those roles). In some forest ecosystems, areas of old growth forest dominated by stands of large old trees have been specifically targeted for protection from logging and other kinds of disturbances (Haynes et al., 2006; Lindenmayer et al., 2015b). An additional prescription in some forest types has been to exclude from logging those individual trees above a certain size or which are characterized by important features such as cavities. In agricultural landscapes, individual large old trees may need to be protected from firewood collection, prescribed fire, browsing and soil compaction by domestic livestock and feral herbivores, and excessive nutrients in dung left by livestock (Lindenmayer et al., 2011a) (Fig. 4). Protective measures may include bans on firewood collection (Driscoll et al., 2000) and micro-fencing (i.e. small scale fences) around individual trees and groups of trees to reduce grazing pressure and to control nutrient loading (Lindenmayer et al., 2011a). The protection of large old trees in these kinds of environments also may be promoted by replacing high-intensity set stocking grazing at the paddock level or even entire the farm level with low-intensity cell grazing or holistic grazing in which livestock are moved frequently between paddocks (Lindenmayer et al., 2011a).

Other strategies may be used to protect individual large old trees and small stands of such trees. In North America, raking of leaf litter and other fine fuels prior to low-intensity prescribed burning is used to protect large old Ponderosa Pine (*Pinus ponderosa*) trees from high-severity wildfire (Kolb et al., 2007). In Yosemite National Park, California, small-scale fire breaks and specially constructed water sprinkler systems were established to protect groves of iconic Giant Sequoia (*Sequoiadendron giganteum)* from wildfire in 2013 (Alexander, 2013).

Protective buffers of other vegetation may be required around individual large old trees and small stands of such trees to protect them from potential threats such as windthrow, fire, and drift from chemical sprays. Other trees in these buffers might also be recruits to eventually replace existing individual large old trees after they have died and collapsed. The size of protective buffers will vary depending on several factors including the kinds of threats affecting large old trees and the distance over which threats can be mitigated. Inadequate buffers have resulted in devastating impacts on individual large old trees; the largest known tree in Australia was killed by Forestry Tasmania as a result of fire and logging in the adjacent environment (Lester, 2010). Similar effects are commonplace elsewhere in south-eastern Australia (Lindenmayer et al., 2015a) (Fig. 5).

Appropriate buffers around individual large old trees may help achieve other objectives beyond tree protection. For example, if the protection of individual large old trees is also designed to conserve particular threatened animal species, the size of buffers may need to make provision for sufficient suitable foraging habitat surrounding a given tree. In Victorian Mountain Ash forests, buffers of 1 km radius were recommended by Lindenmayer et al. (2013) in a study of enhanced forest management prescriptions as a way to promote the protection of stands supporting large old trees occupied by colonies of the Critically Endangered Leadbeater's Possum. Maps of both individual large old trees and associated buffers can be useful for resource managers in planning logging (Fig. 6).

4.1.4. Sustainably manage

Maintenance of populations of large old trees should be a mandatory part of ecologically sustainable forest management as well

Fig. 5. An individual large tree that was killed by a burn lit to regenerate logged Mountain Ash forest in the Central Highlands of Victoria. (Photo by D. Blair).

as ecologically sustainable farming, grazing and fire management. In heavily modified landscapes, all individual remaining large old trees may need to be protected because of the negative ecological impacts that can arise when even a small number of trees are lost (Lindenmayer et al., 2013). In Victorian Mountain Ash forests, the ongoing decline of large old trees is increasing the vulnerability of the ecosystem to collapse as determined under formal IUCN Ecosystem Assessment criterion (Burns et al., 2015). In these forests, large old trees occur primarily as small scattered clumps of trees and isolated individual trees as remaining stands of old growth forest now comprise just 1.16% of the entire forest estate (Lindenmayer et al., 2012b). A significant issue is how to distribute large old trees within landscapes subject to ongoing logging operations. One option is to focus large old tree protection on areas such as gullies and riparian zones where such trees are most likely to occur naturally (Lindenmayer et al., 1991) and where timber harvesting operations are often excluded to protect other values such as water quality (Acuña et al., 2017–in this issue). However, this strategy may not adequately conserve species associated with large old trees that occur elsewhere in the landscape (Kavanagh, 1984; McGarigal and McComb, 1992).

Management of populations of large old trees entails both the long-term protection of existing large old trees and ensuring sufficient recruitment of new cohorts of trees to replace existing large old trees when they die. For example, in the agricultural regions of eastern Australia, populations of large old temperate woodland trees are reaching

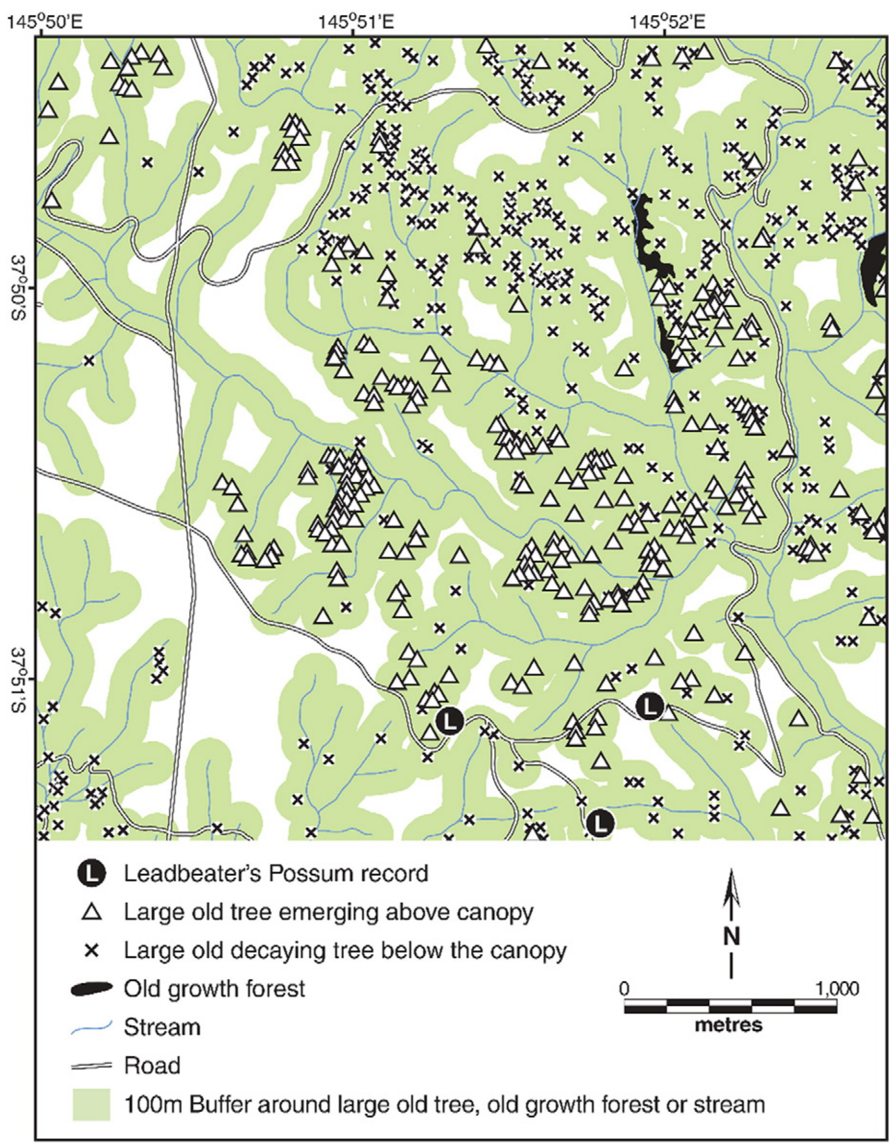

Fig. 6. Map of the location and proposed buffers for large living and dead old trees in the Mountain Ash forests of the Central Highlands of Victoria.

the end of their lives but are not being replaced, in part, because of the impacts of high-intensity grazing by domestic livestock (Manning et al., 2013). This has major implications not only for tree-dependent native biota, but also long-term integrity of agricultural environments through provision of critical ecosystem processes such as pollination services, the regulation of water tables to prevent secondary salinity (Stirzaker et al., 2002) and pest control (e.g. by bats) (Lumsden and Bennett, 2010). Without the maintenance of tree cover through altered grazing regimes to facilitate natural regeneration, the degradation of paddocks will ultimately result in farming practices becoming unsustainable (Fischer et al., 2010).

Efforts to sustainably harvest populations of large old trees can be a major challenge. This is because of the extreme longevity of many species and the prolonged lags times between when trees are lost and new ones of equivalent dimensions (and of similar ecological function) are recruited. Some authors argue that it is rarely possible to sustainably harvest very long-lived organisms because of the profound impacts of adult mortality on population stability and persistence (Caughley and Gunn, 1996). Indeed, the lifespans of some species of large old trees exceeds the lifespans of entire human civilizations, let alone the lifetimes of individual scientists and managers as well as the lifespans of plans for sustainable harvesting that they may propose. Nevertheless, there are strategies for improved sustainable management of large old trees in commodity production landscapes such as those used for wood production. For example, it may be appropriate to quarantine some trees from cutting that would otherwise be harvested and growing them well beyond the age typical of the normal rotation age for logging. Silvicultural systems such as variable retention harvesting in temperate forest ecosystems (Fedrowitz et al., 2014) and reduction intensity logging in tropical forests (Putz et al., 2012) are ways to formally codify harvesting regimes that facilitate the retention of existing individual large old trees and promote the recruitment of new cohorts of large old trees.

4.1.5. Restore

Restoration of large old trees is a major challenge because of the prolonged period between when trees are lost and when new ones with equivalent characteristics and ecological roles can replace them. Some strategies have been employed in an attempt to either restore the roles of large old trees or accelerate tree growth and hence large old tree recruitment so that the roles of these trees can be recreated. An example is the application of strategic ecological thinning in wood production forests and new conservation reserves that have had long histories of past logging where the aim is to grow individual large diameter trees more quickly by releasing retained trees from competition from surrounding trees (Carey et al., 1999; ECC, 2001). This approach has some initial appeal except that larger diameter young trees are not ecologically equivalent to large old trees because many of the features of the latter require prolonged periods of growth, maturation and/or decay to develop. That is, tree age and not just size is important for the development of key features; the most obvious being deep and extended internal cavities (Gibbons and Lindenmayer, 2002) but there are others such as vertically heterogeneous canopies (and lateral subcanopies) (Brokaw and Lent, 1999) and high levels of seed production (Wenk and Falster, 2015). Moreover, thinning to promote accelerated tree girth can sometimes have perverse effects; the accelerated growth of large young trees in the Ponderosa Pine forests of south-western USA can increase the prevalence of ladder fuels which kill neighbouring large old trees (Lindenmayer et al., 2014a). In addition, thinning in some environments can add to the risks of wildfire (Buckley and Corkish, 1991; Forestry Tasmania, 2001) which can subsequently destroy large old trees.

4.1.6. Create

There is a substantial literature on efforts to recreate some of the roles of large old trees via what can be termed "engineering solutions". One of the best known is the establishment of artificial cavities like nest boxes to recreate the cavity provision function of large old trees. Nest boxes can be useful in some circumstances, particularly if appropriately designed and installed (Goldingay et al., 2015) and their use has led to spectacular recoveries of some species (Bruns, 1960; Newton, 1994). However, may have limited value in recreating viable long-term substitutes for natural cavities found in large old trees. As an example, many aspects of the effectiveness of nest boxes for the conservation of cavity-dependent vertebrates have been examined in the wet montane ash forests of south-eastern Australia where populations of large old trees have been severely depleted over the past century. Studies in these forests has indicated there is only a limited period of ~5 years during which nest boxes remain effective before they are either badly damaged by falling branches and/or invaded by pest species (Lindenmayer et al., 2009). Moreover, some species which are in significant decline in Mountain Ash forests, like the Southern Greater Glider (*Petauroides volans*) (Lindenmayer et al., 2011b), do not use nest boxes. Finally, nest boxes make no contribution to the wide range of other ecological roles of large old trees including (among many others) carbon storage, seed production, pulses of flowering, rainfall interception, litter production, and the generation of large pieces of coarse woody debris. Other approaches to promote cavity development in locations where large old trees have been removed include the deliberate damaging of trees to stimulate infection and decay. These approaches have some merit (Bull and Partridge, 1986) but it remains unclear whether they will provide suitable cavities in the long-term and whether, for example, host trees are of sufficient dimensions to support cavities of large enough internal size and volume to enable occupancy by target cavity-dependent taxa.

There is merit in attempts to recreate some of the ecological roles of large old trees such as the provision of nest boxes or instigating cavity creation through the deliberate wounding of trees. However, at the same time, the long-term ecological effectiveness and cost-effectiveness of these strategies remains unknown in many ecosystems (McKenney and Lindenmayer, 1994; Lindenmayer et al., 2009). Moreover, it is critical to ensure that such efforts do not divert the attention away from the need to protect existing individual large old trees.

4.2. Approaches

4.2.1. Incidental

The conservation of populations of large old trees can occur as an incidental "by-product" of traditional broader conservation actions like the establishment of large ecological reserves. In such cases, establishing reserves and thereby removing the human land use drivers of tree loss such as logging, land clearing, or infrastructure development (Crowther et al., 2015) can help secure and eventually increase populations of large old trees. In other cases the distribution of large old trees may shape reserve selection and design (e.g. in Sequoia National Park in California). Conversely (and indeed perversely), drivers of large old trees loss can sometimes be exacerbated within reserves; the impacts of large populations of native herbivores such as elephants in reserves in southern Africa is an example (Vanak et al., 2011). Additional management such as controlling over-abundant animal populations may be required in such cases.

4.2.2. Voluntary

Many people revere individual large old trees and will undertake voluntary action to protect them. Volunteer groups with a strong remit to document, monitor and protect existing individual large old trees are common around the world (Moga et al., 2016; Save the Redwoods League, 2016). For example, voluntary restrictions on cutting large old dead trees for firewood has been triggered in some regions in agricultural south-eastern Australia to promote the protection of iconic species like the vulnerable Superb Parrot (*Polytelis swainsonii*) which use large old trees for nesting. In other cases, the religious significance of some individual large old trees means they are likely to be voluntarily protected (Blicharska and Mikusinski, 2014).

4.2.3. Incentive

Incentive schemes can play an important role in protecting large old trees as small natural features. These include agri-environment schemes (sensu Perkins et al., 2011) that pay private farmers to conduct conservation programs on their farms (Lindenmayer et al., 2012c). In Australia, contracts between the Federal Government and landholders for ongoing incentive payments to conserve woodland on private farmland require individual large old trees to be protected and ensure that natural regeneration occurs (Sato et al., 2016). Similar kinds of programs has been running at the State-level in Australia such as the BushTender initiative (DEWLP, 2016). Incentives in this and other agri-environment schemes can include co-payments to farmers for the establishment of fences around individual large old trees and small patches of associated native vegetation to control grazing pressure by domestic livestock (Lindenmayer et al., 2012c). Importantly, natural regeneration and planting of seedlings around protected individual large old trees appears to promote the health of these trees as well as increase local-scale levels of vertebrate biodiversity (Lindenmayer et al., 2011a).

In other examples, the considerable financial value of particular large old trees from a tourism perspective can create a strong incentive to conserve them. An example is the Great Banyan tree (*Ficus benghalensis*) in the Acharya Jagadish Chandra Bose Botanical Garden near Kolkata (Calcutta) that is considered to be the widest tree in the world. Banyan trees are holy sites for Hindus, the national tree of India and are visited by millions of people annually. In urban areas, prices for real estate can be higher where individual large old trees are present, thereby providing an incentive for owners to maintain such trees on private residential property (Donovana and Butry, 2010). Similarly, the price of farmland supporting tree cover, including large old trees, can sometimes be greater than where most of the native vegetation is removed (Walpole et al., 1998; Luck et al., 2011).

4.2.4. Restrictive

Strict regulation can be needed to protect existing large old trees and facilitate the recruitment of new cohorts of such trees. For example, in wood production forests, logging prescriptions and harvesting bans can be required to enforce the protection of old growth forests where large old trees can be abundant (JANIS, 1997; Lindenmayer et al., 2015b), where there are specified numbers of large old trees, and where trees are above a certain size. Similarly, legal frameworks with associated threats of prosecution can be developed to prevent clearing of individual large old trees as part of the native vegetation cover on private agricultural land (e.g. OEH, 2014).

5. General conclusions

Small natural features are critical components of numerous ecosystems worldwide (Hunter et al., 2017–in this issue). Most small natural features are non-living, abiotic entities (such as rocky outcrops; Fitzsimons and Michael, 2017–in this issue) whereas large old trees are somewhat different in this regard. Large old trees are small natural features in many natural and human-modified ecosystems where they occur as individual trees or spatially-restricted stands comprising a limited number of trees. These trees have a wide range of important ecological roles. A range of strategies can be required to protect individual large old trees and small stands of such trees from ecosystem-specific threats such as logging, clearing, fire and damage by domestic livestock. Protection of large old trees as small natural features will often demand fine-scale management at the individual tree-level, particularly in commodity production environments and urban landscapes where it is generally not possible to establish large ecological reserves. The most appropriate conservation measures to mitigate threats faced by individual large old trees will likely be specific for any given ecosystem, although three general principles are likely to apply in almost all cases. These are: (1) protect existing individual large old trees, (2) reduce the risk of mortality as this is the key part of the life cycle of all long-lived organisms (including large old trees) and has substantial impacts on the dynamics of populations of large old trees, and (3) ensure there are sufficient recruits to replace existing large old trees as they senesce and eventually die.

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