

How introduced animals compound the effects of fire on native plants and animals

Sarah M. Legge, David H. Duncan, David M. Forsyth, Kate Giljohann, Katja Hogendoorn, Rosemary Hohnen, Bronwyn Hradsky and Mark Lintermans

Summary

- Introduced fauna threaten Australia's native species via herbivory, predation, and competition. After fire, these effects can be amplified.
- Post-fire impacts from introduced animals can cause mortality in the months following fire to exceed mortality caused during the fire. The impacts of introduced animals can persist years after the fire event – for example, if fires allow expansion of introduced species into new areas.
- Introduced herbivores influence the greatest range of native species post-fire, affecting plants (consumption, trampling), terrestrial animals (competition, removal of cover), and aquatic animals (trampling riparian vegetation, fouling streams).
- Some introduced species are a particular threat for specific taxa. For example, introduced terrestrial predators threaten many mammals, and introduced fish threaten native fish.
- Control programs for introduced species began quickly after the 2019–20 wildfires, and at increased scales. The open post-fire canopy improved visibility over extensive areas, briefly allowing aerial shooting and baiting to occur in places where such techniques are not usually feasible. The wildfires also reduced populations of introduced species, providing opportunities to achieve suppression.
- Extensive, severe fires provide opportunities to expand introduced species control, such as preventing the reinvasion of introduced fish into streams where they have been extirpated by fire-related sediment pulses; or by delaying apiary activities in forests recovering from fire, so that native species recolonise tree hollows before feral bees.

- Predicting the outcomes of interactions between introduced species and wildfire is crucial for shaping effective and efficient management in future fires, but such predictions will remain challenging until long-term monitoring programs are established that track how populations of introduced and native species respond to wildfires, and if/how management of introduced species supports recovery.

Introduction

Images of blackened tree stems stretching to the horizon and reports of charred animal bodies littering the ground following fires are confronting. Nonetheless many Australian ecosystems have mechanisms to survive fire events: plants may resprout or regenerate from canopy or soil-stored seed (Chapter 9), and many animal species from fire-prone ecosystems can survive the fire event itself either by moving away or sheltering from the flames, heat and smoke. However, after fires, regenerating or recruiting plants, and surviving animals, need to survive extended periods in a post-fire environment with changed habitat structure, resource availability, competition and predation risks. The ability of plant and animal species to survive the post-fire period can strongly depend on their sensitivity to other threats, including introduced animals.

Introduced animal species have had, and continue to have, profound effects on many Australian plants and animals. Introduced herbivores, terrestrial predators, aquatic predators (fish) and invertebrates (such as honey bees) can all exacerbate pressure on populations of native species after fire. Below we present the contextual evidence for compounding effects from key groups of introduced animals, specific observations relating to the 2019–20 wildfires, management responses that were instigated, and priorities for future research and management. At the end of the chapter we summarise the shared themes across these groups of introduced animals.

Introduced herbivores

Introduced herbivores, such as house mice (*Mus musculus*), pigs (*Sus scrofa*), deer (*Cervus* spp.) and feral horses (*Equus caballus*), can have strong direct effects on native species through grazing and browsing, or indirect impacts like trampling, wallowing, compaction and competition for resources. Hooved species (ungulates) are functionally distinct from native herbivores and are typically considered to pose the greatest threat in forested environments, but locally 'overabundant' native herbivores can also become a problem. In some degraded woody ecosystems, herbivores may pose a critical threat even at low to moderate densities, by preventing ecosystem-structuring plants from regenerating (Bennett *et al.* 2020).

Herbivore impacts can be amplified when combined with other key landscape drivers, such as fire and drought. Herbivores may shelter in unburnt areas and then exploit sensitive recovering growth in surrounding burnt areas (Fig. 17.1) (Robinson *et al.* 2013). Larger herbivores also target recently burnt areas for the higher quality forage (Fuhlendorf *et al.* 2009). Post-fire herbivory can reduce vegetation regeneration, recruitment, survival and cover; influence plant community composition (e.g. when more palatable species are targeted); and increase competition for resources with co-occurring native fauna (Tuft *et al.* 2012). Pre- and post-fire, droughts stress ecological communities and may exacerbate herbivore impacts (Giljohann *et al.* 2017). Fires may reduce the abundance of some

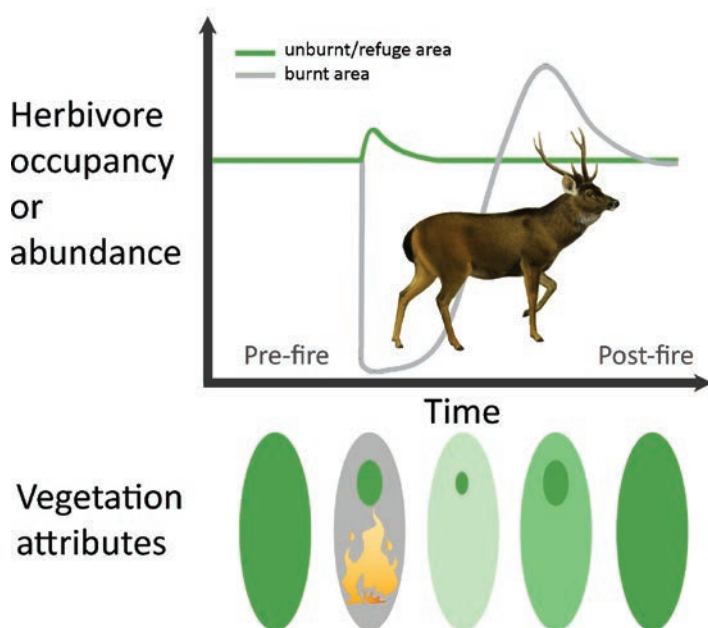


Fig. 17.1. Conceptual model of herbivore response to extensive fire. Herbivore occupancy/abundance is reduced in burnt areas (grey line) but is unchanged (or slightly increased) in unburnt refuges (green line). The post-fire flush of fast-growing, palatable understorey species in burnt areas attracts herbivores. The high food quality and quantity increase herbivore survival and reproductive rates (immigrants and survivors) in burnt areas, maximising population growth there. The herbivore population eventually stabilises, then declines as food quality and quantity change due to forest succession and the pressure of herbivory on understorey plants. The changing vegetation attributes post-fire are indicated by darkening green shading.

introduced herbivores, but only temporarily. For example, Forsyth *et al.* (2012) reported that introduced sambar deer (*Cervus unicolor*) abundance was substantially reduced immediately after the 2009 Victorian wildfires, but that nearly all burnt habitat was reoccupied 24 months post-fire. Similarly, introduced rodents recolonise burnt areas and increase rapidly after fire, outcompeting native rodents for limited food resources and slowing plant recovery (Friend 1993).

Major disturbance events, such as extensive wildfires, may radically alter the risk from herbivores. For example, of 92 ecosystems highly impacted by the 2019–20 wildfires, 11 were considered highly exposed (> 50% distribution) to introduced herbivores post-fire (Keith *et al.* 2022). These included rainforests, wet eucalypt forests, peatlands and subalpine woodlands. European rabbits (*Oryctolagus cuniculus*) and deer were the most pervasive introduced herbivore taxa across affected ecosystems, although feral horses and feral pigs were locally important. In a separate assessment, 97 plant species were considered highly vulnerable to introduced herbivore impacts after the 2019–20 wildfires, and 44 additional plant species were considered at medium risk (Gallagher *et al.* 2021). Excluding large introduced herbivores from regenerating and unburnt vegetation to maintain habitat condition and reduce competition was considered an urgent management action for 62 of 119 priority animal species following the 2019–20 wildfires, and possibly required for an additional 14 priority animal species (Legge *et al.* 2022).

Introduced herbivore control after the 2019–20 wildfires

Following the 2019–20 wildfires, introduced herbivore control was a management focus across many fire-affected areas. For example, the Commonwealth Government invested \$67 million across seven fire-affected regions; in six of those regions, local stakeholders considered that 20–30% of their region's funding should be directed to introduced animal control, with most or all of that for introduced herbivores (<https://www.dcceew.gov.au/environment/biodiversity/bushfire-recovery/funding-support/regional-delivery-program>).

State governments also invested heavily to reduce introduced herbivores impacts. Large-scale aerial shooting programs for deer, pigs, goats (*Capra hircus*) and feral cattle (*Bos taurus*) began immediately after the fires (DELWP 2020; DPIE 2020). Helicopter-based shooting of ungulates can be highly effective in non-forested habitats but is less effective in forests because animals are less detectable. However, severe fires removed the canopy over large areas, presenting a brief opportunity for landscape-scale aerial control in areas where this was not previously possible. State agencies sought not just to reduce immediate post-fire impacts, but also to reduce the populations of ungulates for longer-term benefit (DPIE 2021). For example, on Kangaroo Island the 2019–20 wildfires killed many feral pigs, and the South Australian Government is leveraging this opportunity to try to eradicate pigs from the island by 2023 (Korcz 2020).

Future research and management

The value of reducing herbivore populations post-fire is widely assumed, but has not been quantified. We know little about how population density, movement dynamics, or occupancy of introduced herbivores change after extensive fire, or how these attributes relate to herbivore impacts post-fire (but see Forsyth *et al.* 2012). These knowledge gaps limit optimal allocation of resources to remediation actions across the landscape after extensive fires. There are also few studies that explore how fire–herbivore interactions are conditioned by other threats (e.g. timber harvesting, disease, predation), variation in fire characteristics (e.g. extent, severity), and changing climate (including rainfall or temperature anomalies). Severe fires often follow years of below-average rainfall (Chapter 2) and, as novel conditions resulting from Anthropogenic climate change continue, studies that evaluate the interaction between herbivores and fire under a range of conditions are needed.

Field surveys can reveal the immediate impacts of fire and post-fire herbivore activity; however, only long-term monitoring can uncover whether these immediate responses will have ongoing detrimental impacts on native species or communities. However, given the stochastic nature of extensive and severe fire, and the complexity of interacting factors, modelling and simulation are also critical for investigating the knowledge gaps outlined here.

Introduced terrestrial predators

Two introduced predators (red fox (*Vulpes vulpes*), feral cat (*Felis catus*)) have had substantial impacts on Australian native species, especially terrestrial small to medium-sized mammals, ground-dwelling birds, and other species that live on or near the ground (Stobo-Wilson *et al.* 2022). Fire may amplify the predation risk for these animals, for several reasons (Fig. 17.2):

- Understorey vegetation, leaf litter, coarse woody debris and hollow trees provide important shelter for native species; their consumption by fire may increase the hunting success of predators.

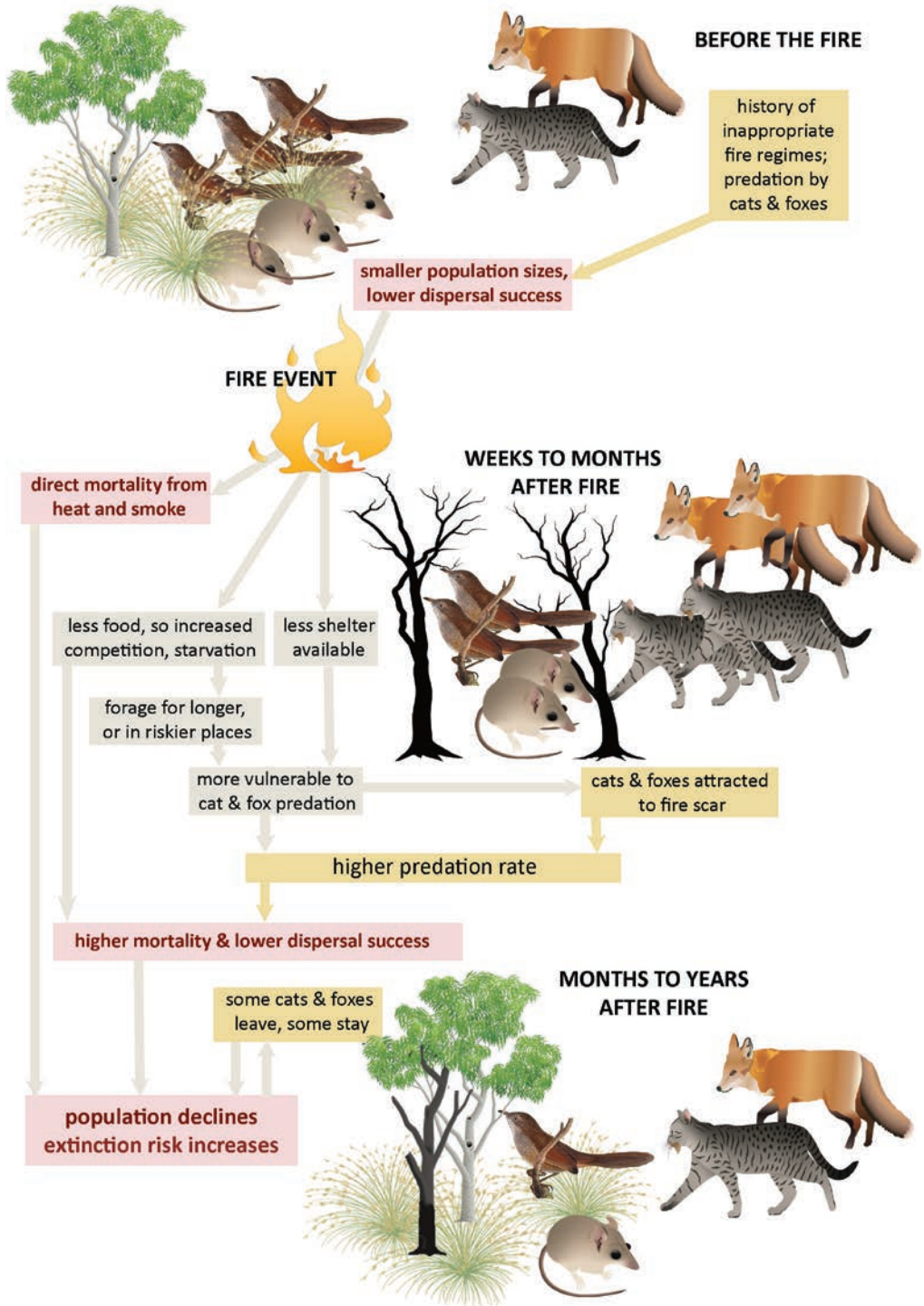


Fig. 17.2. A summary of the mechanisms by which introduced terrestrial predators affect native species pre- and post-fires.

- If fire reduces food availability for native species (or increases competition), individuals may forage for longer or in riskier locations, again increasing the hunting success of predators.
- Opportunities for greater hunting success may, in turn, attract predators to burnt areas, further increasing predation pressure on native species.
- Reductions in native animal population size or population connectivity post-fire (from any cause), reduces the resilience of surviving populations to ongoing predation pressure.
- Populations of native species may already be small and fragmented pre-fire due to prevailing threats including predation from introduced predators, drought, and inappropriate fire regimes. Small, isolated populations are intrinsically more vulnerable to additional losses, caused directly or indirectly by fire, and less likely to recover through reproduction or immigration.

Foxes and cats use fire scars intensively in the weeks post-fire. In south-eastern Australia, foxes with home ranges that overlapped prescribed burns intensified their use of these areas immediately post-fire (Hradsky *et al.* 2017). Similarly, in northern Australian savannas, cats selectively used burnt areas in the first two months post-fire, with individuals travelling up to 13 km from their home range to access some fire scars (McGregor *et al.* 2016). Unburnt patches within large fire scars may be especially attractive if prey densities along the burnt-unburnt edges are high (Parkins *et al.* 2018). The attractiveness of fire scars to foxes and cats appears short-lived – in the order of weeks to a couple of years – perhaps reflecting declines in prey availability from population suppression or declines in hunting success from habitat recovery (Hradsky 2020).

Diet studies have shown that foxes increase their relative consumption of mammals post-fire (Green and Sanecki 2006), concentrating on medium-sized native mammals such as bandicoots, possums and echidnas (Robley *et al.* 2016; Hradsky *et al.* 2017). The effects of fire on cat diet have not been studied, but in north-western Australia, the small mammal mortality rate increased 20-fold after severe fire due to predation, including by cats (Leahy *et al.* 2016), and cats hunted more efficiently in burnt areas (McGregor *et al.* 2015); so the mammal component of cat diet may have increased post-fire.

Since introduced predators are attracted to burnt areas and hunt more efficiently there, it is unsurprising that several studies have shown that fire increases the vulnerability of small to medium-sized native mammals, reptiles, and ground-dwelling birds to foxes, cats, and also to native predators (e.g. Leahy *et al.* 2016; Moore *et al.* 2018; Comer *et al.* 2020). These studies occurred after much smaller fires than the 2019–20 wildfires. Very large, severe fires may also cause substantial mortality to cats and foxes, potentially lowering predation risk to native animals that survive the fire. However, if prey populations are reduced, and are more accessible to predators, the net predation risk after large severe fire may still increase. For example, on Kangaroo Island, cat activity decreased by ~60% after severe fire and had not recovered a year later (Box 17.1). Cats on Kangaroo Island were attracted to small unburnt habitat patches that harboured refuge populations of native mammals (Chapter 24), suggesting that cat impacts in these areas could exceed pre-fire impacts. In another example, long-footed potoroo (*Potorous longipes*) populations in Victoria were much less likely to occur in areas burnt severely in the 2019–20 wildfires compared to unburnt locations. They were also substantially more likely to occur at sites with lower predicted fox densities (DELWP 2021).

Predation is probably the main pathway through which foxes and cats affect native prey species post-fire, but other effects are possible. Native predators including goannas

(*Varanus* spp.) and spotted-tail quolls (*Dasyurus maculatus*) may experience increased competition for prey, if all predators must compete for a smaller resource base. In another example, foxes and cats may capitalise on introduced rodent and rabbit populations if these recover more quickly than native prey post-fire. This might dampen the population increase of the introduced prey, but could also maintain fox and cat populations at elevated densities, delaying recovery by native species. We know very little about these potential pathways, but some likely interactions have been described elsewhere in Australia (e.g. Glen 2014; Pedler *et al.* 2016).

Box 17.1. Post-fire changes in feral cat abundance on Kangaroo Island

Much research into the response of feral cats to fire has occurred in northern Australia, with fewer studies from southern Australia, where fires are less frequent but typically much more intense. Assessing the impacts of large, intense fires on feral cats is inherently difficult as the location and timing of these fires is difficult to predict, so such studies require a chance overlap between fires and an area where predator monitoring has occurred.

The 2019–20 wildfires were the largest in Kangaroo Island's recorded history, burning 46% of the island, including most of the conservation reserve network, and mostly at very high severity. Opportunistically, we were able to examine the impact of this fire on the island's feral cat population, because of a baseline sample just before the fire (Hohnen *et al.* 2021). Sampling of these same sites was conducted 3–8 months post-fire (five sites in burnt areas; two sites in unburnt areas) (Fig. 17.3), and three of these sites were resampled one year after the fire

Three to eight months post-fire, at sites that were burnt by the severe fire, the number of individual cats declined by 57% and the nightly detection rates declined by 65%, compared to pre-fire levels. At the two burnt sites resampled a year post-fire, cat activity was still less than half that of pre-fire levels, suggesting no or limited recovery.

Although post-fire cat activity was lower in burnt areas, the remaining cats could still inhibit recovery of (much-reduced) native wildlife populations, particularly if they



Fig. 17.3. A feral cat on Kangaroo Island.

targeted small unburnt vegetation patches, where surviving wildlife likely congregated. On Kangaroo Island, and other areas burnt by high-severity fires, feral cat control may be important to support recovery of populations of fire-affected species. Such emergency interventions are likely to be required more frequently as the climate warms and fire frequency, severity and extent increase.

Introduced predator control after the 2019–20 wildfires

Of 76 mammal, bird, reptile and frog species prioritised by the Commonwealth Government for management intervention after the 2019–20 wildfires, introduced predator control was considered urgent for 30 species, and possibly required for an additional 23 species (Legge *et al.* 2022).

Given the threat from introduced predators, government and non-government organisations intensified their control programs post-fire. In South Australia, the Kangaroo Island Landscape Board, in conjunction with the National Parks and Wildlife Service, began controlling cats in state-owned areas on the island, while a local non-profit organisation (Kangaroo Island Land for Wildlife) did so within a network of private landholders (see Chapters 24, 25). Trapping and poison-baiting occurred across the fire scar to reduce cat impacts on fire-affected threatened species, including the Kangaroo Island dunnart (*Sminthopsis griseoventer aitkeni*) (DEW 2020). Over 1100 cats were removed in the 2 years following the fires (M. Heard, P. Jennings, H. Groffen, P. Hodgens, *pers. comm.*). One unburnt site with surviving dunnarts was encircled by a cat-proof fence (Chapter 24), and artificial ground shelters were installed on private properties to provide refuge for native animals from feral cats (Dickman and McDonald 2020).

In New South Wales, the National Parks and Wildlife Service increased the spatial scale of poison-baiting fivefold immediately after the 2019–20 fires, and have maintained baiting operations since then (DPIE 2020, 2021). Preliminary monitoring data show that wild dog and fox activity decreased in some areas, although decoupling declines from seasonal patterns is challenging. Cat activity has not shown a consistent change in response to the baiting (P. Mahon, *pers. comm.*). In Cape Arid National Park, on the south coast of Western Australia, the Department of Biodiversity, Conservation and Attractions intensified cat control around the western ground parrot (*Pezoporus wallicus flaviventris*) population, with additional aerial and ground baiting, followed by trapping and culling, in the summer and spring following the fires (S. Comer, *pers. comm.*).

In Victoria, the Department of Environment, Land, Water and Planning used biodiversity models and expert workshops to develop a strategic fire response with prioritised cost-effective actions. As part of a theme of 'Intensified and sustained management of threats', > \$3 million was invested to control foxes and feral cats in the first 3 years post-fire. The control programs are collaborative and landscape-scale; they target burnt and adjacent unburnt areas that are likely to give the greatest return on investment and benefit the full range of species across Victoria. Actions include re-establishing Southern Ark (a landscape-scale fox management program in East Gippsland), and infilling and expanding this program by another 100 000 ha; expanding the Barry Mountains fox control program, with a focus on protecting the endangered long-footed potoroo; controlling foxes to protect threatened species such as brush-tailed rock-wallabies (*Petrogale penicillata*) in the Upper Snowy River and Little River regions; baiting and trapping for foxes

across public and private land in fire-affected areas; and piloting feral cat control programs within priority areas.

Future research and management

The efficacy of predator control for supporting the persistence of native species after fire is poorly studied (Bendall *et al.* 2021). Thus, monitoring data (of predators and prey) from the predator control programs currently underway will inform responses to future fires. Given what we know about fire and introduced predator interactions, landscape-scale control of introduced predators, coupled with intensive management (including artificial refuges, fencing) at sites with small populations of susceptible species, seems the best combination of post-fire actions. However, although this approach may be feasible for foxes, there is no landscape-scale control approach for cats in eastern Australia, and this is a serious implementation gap. Improving our understanding of how to manage post-fire predation pressure to support native species survival, recruitment, population density and persistence remains a priority.

Introduced invertebrates: the honey bee

Honey bees (*Apis mellifera*) were introduced into Australia in the 1820s. Helped by our mild winters and abundant, nectar-rich trees, honey bees have become feral in much of temperate and subtropical Australia. Feral honey bees can reach high abundance if they have access to fresh water and high densities of old eucalypt trees, whose hollows are perfect for nesting bee colonies; densities can exceed 160 colonies/ha (Wood and Wallis 1998).

Honey bees affect Australian native biota in several ways. They pollinate many native plant species, but they also pollinate weed species, alter plant-pollinator networks and seed-set patterns, and transmit bee and plant pathogens (Mallinger *et al.* 2017). Feral honey bees compete for hollows with birds and mammals (Berris and Barth 2020). In addition, because of their sheer numbers, their ability to forage at lower temperatures than solitary bee species, and because they can rapidly recruit foragers to rich resources through dancing, honey bees can outcompete nectarivorous birds, native bees and other insects for floral resources (Paton 2000; Mallinger *et al.* 2017). Such resource depletion could in turn reduce food availability for insectivorous vertebrates, which generally do not feed on honey bees due to their powerful defensive stings. However, this has not been investigated.

The effect of fire on feral honey bees is little studied. Overseas, opportunities to examine these issues are limited, as feral bee densities are often extremely low due to the effects of *Varroa* mite and associated viruses (Oldroyd 1999). While the effects of fire on bee composition and plant pollinator networks have been investigated in several countries (Ne'eman *et al.* 2000; Banza *et al.* 2021), the studies generally pertain to small burnt areas (60–450 ha), much smaller than the 10 km honey bee foraging and dispersal range. However, some inferences can be made from the limited information available. During intense fires, colonies in trees will burn, heat can melt the wax, or smoke can kill bees directly. However, feral colonies in caves and under cliffs may be unaffected. Feral hives high up in the trees may survive low severity fires that pass under them. After the fire, the burnt landscape will temporarily contain few floral resources. This is likely to have caused some feral honey bee populations to decline after the 2019–20 wildfires.

Feral honey bee recolonisation rates after fire depend on whether fresh water and nesting opportunities (tree hollows) are available (Fig. 17.4), the size of the area burnt, the size of the source population of managed and feral colonies at the edge of the burnt area, and whether



Fig. 17.4. Feral honey bees compete with native species for tree hollows. (Photo: Keith J. Smith/Alamy)

managed hives are allowed into the recovering bushland. Fire can promote tree hollow creation, causing more hollows to be available for feral honey bees. However, fires, especially repeated fires, can remove hollows as trees with existing hollows burn readily. This would increase the competition for remaining hollows. Hollow recolonisation is likely to be rapid: depending on the conditions, colonies produce 0.9–3.6 swarms/season (Oldroyd *et al.* 1997), and swarms can disperse up to 10 km (Villa 2004). In Australia, re-occupation rate after eradicating all colonies in a 500 ha area was 15 colonies/km² per year (Oldroyd *et al.* 1997).

Once floral resources recover, feral honey bees are likely to rapidly recolonise forested areas after burns. Where fire increases hollow availability, bees are likely to return in higher densities than before; where fire reduces hollow availability, competition between honey bees and native hollow-nesters will increase. Thus, recolonisation is likely to affect the recovery of native ecosystems after fire through competition with native species for floral resources and hollows, and through pollination of weeds.

Future management

Eradication of feral honey bees in native vegetation is not possible (Oldroyd 1998). Prohibiting beekeeping within and near burnt forests could help delay recolonisation by feral honey bees.

Aquatic systems: fire and introduced fish

Post-fire rainfall events can devastate fish populations when high surface flows and erosion causes ash and sediment slugs in streams that travel 50–80 km downstream of the burnt

area (Lyon and O'Connor 2008; Silva *et al.* 2020; Chapter 6). Sedimentation can cause immediate fish mortality events, and can have longer-term impacts by simplifying substrates and infilling pools. These effects can interact with introduced, invasive fish species either negatively or positively and an example of each is presented below.

Fire impacts can alter instream habitats for years or decades, disadvantaging species with specialist habitat requirements and benefitting generalist species. For example, fish species that require particular substrates as breeding or refuge sites (e.g. cobble for two-spined blackfish (*Gadopsis bispinosus*); Lintermans 2007), or high habitat diversity for a range of ecological needs (such as feeding, courtship and spawning) will be disadvantaged, particularly in aquatic environments impacted by other anthropogenic stressors such as flow regulation (Leprieur *et al.* 2008). Invasive species are often more 'generalist' than native species, with wider temperature, salinity and physiological tolerances; larger body size, dispersal capacity, longevity, higher fecundity and delayed maturation. They can adapt to living in altered habitats, and rapidly populate degraded areas (Liu *et al.* 2017). Consequently, invasive species can potentially take advantage of altered ecological conditions and widely disperse into such environments following disturbances (Dunham *et al.* 2003). Following the 2019–20 wildfires, trout (*Oncorhynchus mykiss*, *Salmo trutta*) abundance rapidly rebounded within 12 months after initially being severely reduced (~80%) post-fire (M. Lintermans, unpublished data). Similarly, in lowland rivers, highly invasive carp (*Cyprinus carpio*) and gambusia (*Gambusia holbrooki*) are expected to rapidly rebound to the detriment of native species (Koehn 2004).

For 16 fish species prioritised by the Commonwealth Government for management intervention following the 2019–20 wildfires, controlling invasive fish was considered a potential action for eight species. Invasive fish were also considered to threaten up to eight of 22 priority spiny crayfish species, and up to five frog species (Legge *et al.* 2022).

Alternatively, fire impacts on invasive fish can present conservation opportunities. In upland environments, invasive trout prey upon small native fauna such as galaxias and spiny crayfish (McCormack 2012; Jarvis *et al.* 2019). Surveys in 2020 of fire-impacted streams in the NSW Alps recorded 'fishless' streams, where trout had probably been extirpated by ash and sediment slugs. If such extirpations occur upstream of barriers to trout recolonisation, these fishless streams present opportunities to reintroduce native fish, including the many threatened galaxias species (Lintermans *et al.* 2020) that generally cannot coexist with trout (TSS 2006; Jarvis *et al.* 2019). Occasionally, galaxias can naturally recolonise streams after trout are removed, if upstream refugial populations of galaxias persist (Lintermans 2000).

Future research and management

Identifying instream barriers to invasive fish colonisation would inform threatened fish reintroductions (Jones *et al.* 2021) and help prioritise native species reintroductions. New remote-sensing methodologies for detecting barriers (LIDAR and drones) are promising (Allan and Lintermans 2021). If invasive fish populations are extirpated upstream of partial barriers, these barriers could be augmented, but the action would need to be rapid (trout are very mobile and would soon recolonise fire-affected streams once partial barriers are breached (Dunham *et al.* 2003)). Where barriers prevent natural recolonisation (e.g. waterfalls > 2 m height, large dams), then recreational fish stocking and other human activities that bypass barriers should be prevented. Trout stocking programs to boost reduced populations are common following natural 'disasters' such as drought or fire, so dialogue between fish stocking agencies, angler groups and threatened fish managers is needed to capitalise on opportunities for fish conservation.

Conclusions

Fire tends to amplify the impacts of herbivory, predation and competition by introduced animals on native species. Our understanding of the interactions between introduced species and fire is based on studies of fire events much smaller than those of 2019–20. However, increasingly large and severe fires will be likely to worsen the impacts of introduced animals. Across animal groups, introduced herbivores affect the greatest range of native species. Of the 119 animal species prioritised for management intervention after the 2019–20 wildfires by the Commonwealth Government (Legge *et al.* 2022), introduced herbivore control was a key management action for 62–76 species across vertebrates and invertebrates; introduced terrestrial predator control was a key action for 30–53 species (mammals, birds, reptiles, frogs); and introduced fish control was identified as a key action for 3–21 frogs, fish and spiny crayfish species.

Fires, especially extensive, severe fires, can also provide opportunities to control introduced species more effectively, if access is improved (e.g. aerial shooting of ungulates in severely burnt forests); if the introduced species' population size is much reduced (e.g. feral pigs on Kangaroo Island); or if the introduced species becomes concentrated in areas and can be targeted more efficiently (e.g. cats hunting in unburnt fragments). In some situations, fires could provide novel conservation opportunities when populations of introduced species are extirpated, such as when post-fire sediment influxes to streams kill trout populations, making sites available for reintroductions of native species that were previously eliminated by trout.

For most Australian biodiversity, there is little or no long-term monitoring, making it difficult to assess the impacts of unexpected events. High-severity fire is likely to be increasingly frequent in temperate and subtropical forests; we urgently need monitoring programs to understand how populations respond to these fires, how threats such as introduced species affect that response, and how introduced animal management can support recovery.

Recommendations

- Interactions between fire and introduced animal species are a key pathway by which wildfire affects native species; therefore enhanced landscape-scale management of introduced species will help build resilience of native species to wildfire.
- After fire, landscape-scale control of introduced animal species across the burnt areas and adjacent unburnt areas, coupled with intensive management at sites with small populations of susceptible native species, needs to occur rapidly (days to weeks).
- Pre- and post-fire monitoring should be substantially enhanced to understand the impact of fires on the distribution, density and movement patterns of introduced species; their impacts on native species; and the efficacy of management interventions.
- We need a better understanding of how the interactions between fire and introduced species are themselves affected by other threats.
- A landscape-scale control option that is cost-effective for feral cats needs to be developed.
- Beekeeping within and near sites recovering from fire should be prohibited.
- The existing barriers to invasive fish should be identified, and partial/incomplete barriers augmented to create river reaches that could support native fish reintroductions when invasive fish populations are extirpated by fire.
- Recreational fish stocking policy and behaviours should be modified to support rather than compromise native fish reintroductions.

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