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The impacts of the 2019–20 wildfires on Australia's lizards and snakes

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Summary

Context and challenges

- Australia harbours a disproportionate share of global squamate diversity (lizards and snakes). The areas impacted by the 2019–20 wildfires comprise diverse squamate communities that include many threatened and narrowly distributed species.
- The impact of fire on most Australian squamates is not well understood. Reptile populations are monitored less than any other vertebrate group, and many species have unresolved taxonomy.

Main findings

- Very few studies have considered the effects of fire on squamate mortality or how attributes of fire regimes affect squamates in areas impacted by the 2019–20 wildfires.
- The habitat of 445 squamate species from 11 families was within the footprint of the 2019–20 wildfires, representing nearly 40% of Australia's described species. This included 29 species listed as threatened nationally or globally.
- One species, Kate's leaf-tailed gecko (*Saltuarius kateae*), had its entire known (highly restricted) range burnt, but post-fire sampling indicated that the species persists and is breeding in the firegrounds.
- Species in most need of monitoring and conservation following the 2019–20 wildfires are narrowly distributed species with moderate-to-high fire overlap and traits that make them vulnerable to fire and post-fire conditions.
- Assessments of within-species diversity across 14 priority species identified 19 evolutionarily significant units and more than 18 management units.
- Assessment of the on-ground effects of the 2019–20 wildfires is hampered by a lack of long-term monitoring and investment. There is an urgent need to break a cycle of chronic under-funding of reptile monitoring and conservation in Australia, particularly given the increasing prevalence of large, high severity wildfires.

Introduction

Although Australia accounts for only 5% of the world's landmass, it supports ~10% (~1130) of the ~11 690 reptile species on Earth (Uetz *et al*. 2021), most of which are terrestrial squamates (lizards and snakes). From remote rock atolls in frigid seas off the coast of Tasmania to the canopies of wet tropical rainforests through Far North Queensland, and from alpine meadows to arid deserts, lizards and snakes inhabit the entire Australian continent, and 96% are found nowhere else (Chapple *et al*. 2019). Australia has had three documented squamate extinctions since European invasion (Woinarski *et al*. 2019), and 6–11 more have a high likelihood of extinction in the next 20 years (Geyle *et al*. 2021). Currently, 7.1% of Australian squamates are threatened with extinction (IUCN 2021). Lizards and snakes (collectively squamates) comprise most of Australian reptile species and are the focus of this chapter. We recognise that the 2019–20 wildfires also affected some of Australia's freshwater turtle species, but these are not considered here (but see Chapter 6 for information on impacts of these fires on aquatic systems, and Chapter 27 for information on one fire-affected turtle species).

While many Australian ecosystems have a deep evolutionary history with fire, most populations are not adapted to fire *per se*, but to *fire regimes* (frequency, interval, season, intensity, severity, and spatial aspects of fire; Gill 1975). Fire regimes vary across Australia from rainforests that experience fires once every 100 years, to tropical savanna ecosystems that experience fires every 1–5 years (Murphy *et al*. 2013). Globally, fire regimes have shifted over recent centuries, and altered fire regimes are regarded as an extinction threat to thousands of species (Kelly *et al*. 2020). Of the 60 Australian terrestrial squamates considered most at risk of extinction, approximately a third have altered fire regimes listed as a threat (Geyle *et al*. 2021). Altered fire regimes are regarded as a threat to 79 squamate species, and many of these occur within the regions affected by the 2019–20 wildfires (Tingley *et al*. 2019).

Key findings

Australian squamates and fire: what is the state of knowledge?

We undertook a global review of studies of the immediate impacts of fire: those that track the fate of squamate reptiles through the path of a fire and assess what proportion of animals live and die (see Jolly *et al*. 2022 for details). We found six such studies, all from North America (n = 4) or Australia (n = 2). These studies tracked an average of 14 individuals (range = 1–61) through fire, reporting mortality rates of 0–50% (Durbian 2006; Hellgren *et al*. 2010), with an average mortality rate of 15%. Both studies conducted in Australia are noteworthy. One study of the pygmy bluetongue lizard (*Tiliqua adelaidensis*) tracked eight individuals through an intense grassfire (Fenner and Bull 2007). The lizards sheltered in spider burrows during the fire, and all survived. Another tracked frill-necked lizards (*Chlamydosaurus kingii*) through two fires in northern Australia (Griffiths and Christian 1996). The first was an early dry season fire, which are usually of low intensity. All 17 of the lizards that were radio-tracked survived the fire by remaining in the tree canopy. The second was an intense, late dry season fire. This time, animals that remained in treetops died, whereas animals that escaped to termite mounds survived. Overall, a quarter (6) of the 24 frilled lizards died during the late dry season fire, with another succumbing to fire-caused injuries sometime later. Animal survival during fire is the outcome of a complex interplay between animal behaviour, the environment (e.g. the provision of refuges) and fire attributes (e.g. intensity, rate of spread) (Jolly *et al*. 2022).

We identified 69 papers from across Australia that examined the direct or indirect impacts of fire on squamates (Fig. 14.1). Most of the research (> 90%) compared the occurrence or composition of squamates at sites that differed in their most recent fire history (e.g. burnt *v.* unburnt sites or sites that differ in their time since fire). These studies have demonstrated that fire can impact squamates for decades (Dixon *et al.* 2018), primarily through its impact on habitat (i.e. vegetation structure), although, in some instances, recovery is rapid. Far less is known regarding how other elements of the fire regime affect squamate populations or communities. Of the 69 published studies, only three (4%) considered the impacts of fire severity, four considered fire intensity (6%), 11 considered fire frequency (16%), three considered fire interval (4%), seven considered fire season (10%), and nine considered spatial aspects of fire (13%) (Fig. 14.1). While there is a good spread of studies across Australia that have examined how the most recent fire affects squamate populations and communities – including numerous studies within the analysis area (Fig. 14.1) – studies of other aspects of the fire regime are few and geographically clustered. This lack of published research severely hampers our capacity to understand the likely ramifications of the 2019–20 wildfires on squamate species and communities.

The 2019–20 wildfires: which species were most affected?

The simplest means of assessing which species were potentially affected by the 2019–20 wildfires is to assess 'fire overlap', which is the proportion of a species' geographical range within the fire footprint. It is important to differentiate this notion of 'affected' species from the on-ground impacts of the fires. Species may have high fire overlap, but how that plays out on the ground – the actual impacts of the fires on individuals and populations – could range from minimal to substantial. With this in mind, the 2019–20 wildfires affected 445 squamate species, constituting 39% of Australia's 1128 described reptile species and 42% of Australia's 1051 terrestrial squamate species (Uetz *et al.* 2021). The fires overlapped the distributions of squamate species from 11 families (Fig. 14.2): Scincidae (n = 199; 43%), Elapidae (n = 67; 61% of terrestrial elapids), Diplodactylidae (n = 45;

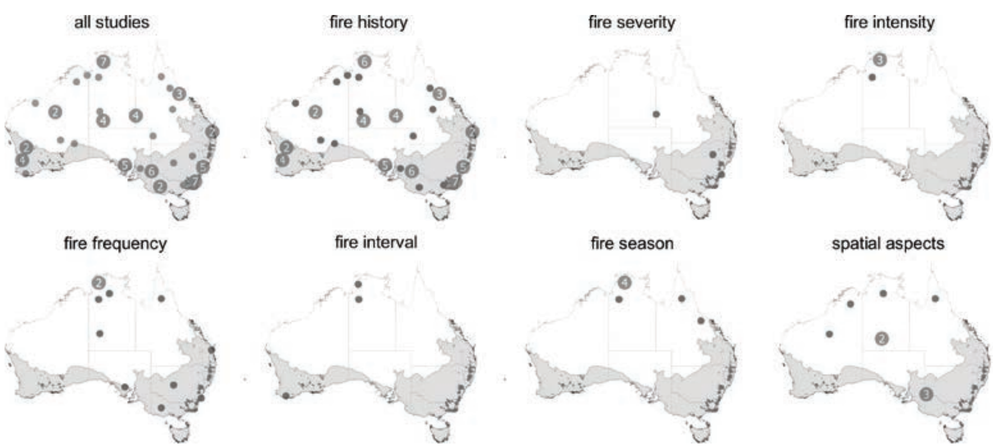

Fig. 14.1. Studies investigating the responses of Australian terrestrial squamate reptile populations or communities to fire. Light grey = analysis area. Dark grey = 2019–20 wildfires. Circles represent the location of studies and numbers within circles refer to the number of studies (when > 1). 'Fire history' refers to studies that consider only the most recent fire (e.g. time since fire/burnt versus unburnt/before versus after fire), and no other elements of the fire regime.

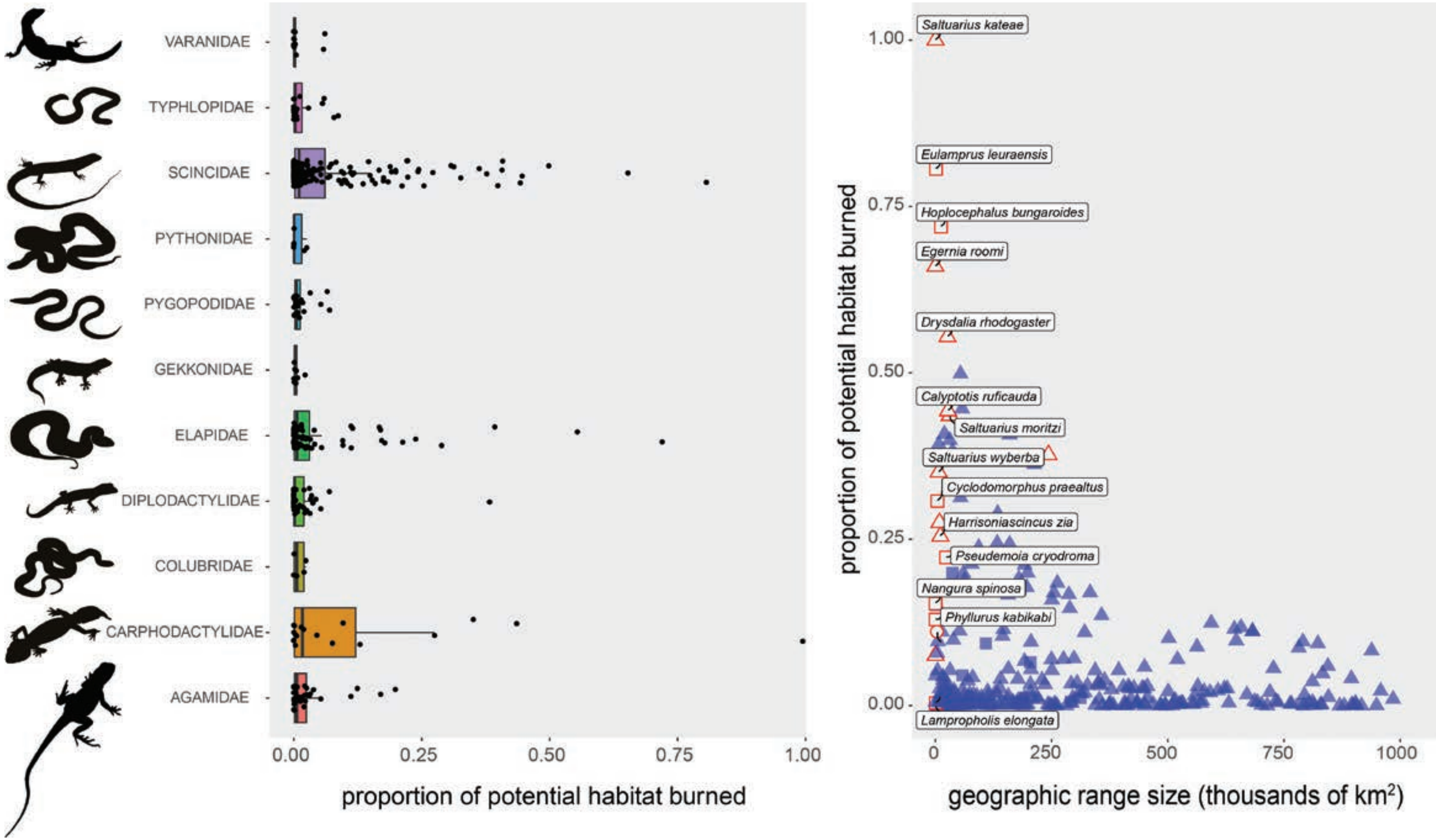

Fig. 14.2. Summary of overlap between Australian terrestrial squamate species' geographical ranges and the 2019–20 wildfires. (Left) Species' overlap by taxonomic family, and (right) comparison of species' overlap with species' geographical range size (for species with geographical ranges < 1 million km^2). Priority species are hollow with a red outline, non-priority species are dark blue. Squares = species threatened under either the EPBC Act or IUCN, triangles = unlisted species, circles = data deficient species (according to IUCN). Examples of priority species are labelled. Overlap estimates are derived from IUCN range maps and species distribution models when available.

Fig. 14.3. Overlap between the Australian 2019–20 wildfires and a subset of the federal government's priority reptile species. Dark grey = the 2019–20 wildfires (from NIAFED), and different colours show the geographical range of different species. Conservation status is derived from the EPBC Act or the IUCN Red List. (Photos: Brendan Schembri (*C. reticulatus* and *E. leuraensis*), Jules Farquhar (*C. praealtus* and *P. cryodroma*), Chris Jolly (*H. bungaroides*), Matt Greenlees (*S. kateae*))

44%), Agamidae (*n* = 38; 35%), Pygopodidae (*n* = 28; 62%), Typhlopidae (*n* = 20; 41%), Carphodactylidae (*n* = 18; 56%), Varanidae (*n* = 11; 37%), Gekkonidae (*n* = 8; 11%), Pythonidae (*n* = 6; 40%), and Colubridae (*n* = 5; 100%). This included 29 species listed as threatened under either the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) or the International Union for Conservation of Nature (IUCN) Red List. However, these measures do need to be interpreted with caution. Of the 445 species with some fire overlap, the majority (*n* = 243 species) had < 1% of their range affected (Fig. 14.2). Given the coarse nature of both species range maps (mostly IUCN range polygons) and the national fire maps (the National Indicative Aggregated Fire Extent Datasets, DAWE 2020a), these latter species may equate to 'rounding errors' that bear little relationship to the on-ground situation. More relevant are those estimates of overlap that exceed 10%. Here, we find 44 species with 10–30% of their range affected, 15 species with 30–50% of their range affected, three species with 50–80% of their habitat affected, and two species with > 80% of their range affected, including one (Kate's leaf-tailed gecko) whose entire known geographical range overlapped with the fire footprint (Fig. 14.3, Box 14.1, Fig. 14.4).

Box 14.1. Kate's leaf-tailed gecko

Situated in the Northern Rivers region of New South Wales, between the Richmond Range and the Clarence River, lies a unique escarpment known as the Kangaroo Creek Sandstones – home to Kate's leaf-tailed gecko. Kate's leaf-tailed gecko is a relatively large gecko, ~20 cm from nose to tail. Like other members of this genus, its 'flat' body allows it to shelter in the narrow cracks and crevices in the sandstone outcrops with which it is exclusively associated (Fig. 14.4). Until 2020, there were fewer than 20 official records of the species from a tiny area around Mount Marsh and Mount Neville. The entire area from which this species was known burnt during the 2019–20 wildfires. This made Kate's leaf-tailed gecko the only known vertebrate species in Australia whose entire range was affected by the fires. Federal and state government conservation agencies and the local community were all greatly concerned about the species. Following the fires, the Border Ranges Richmond Valley Landcare Group won funding to conduct surveys for Kate's leaf-tailed gecko to determine the impact of the fires. Before the fires, there was only a limited understanding of where the gecko occurred, and no information on trends in its population or threats to the species. Since late 2020, surveys conducted in the area have determined that the geckos fared remarkably well despite the fires. In larger expanses of the outcrop, geckos were recorded in numbers that were equivalent to the maximum number detected in an area when the species was first discovered and described. Juvenile geckos were detected too, suggesting that the fires had not prevented recruitment. Surveys have detected them at sites where they had not previously been recorded, expanding the known distribution of the species. Despite their small range, the geckos' strong association with the rocky habitat seems to have afforded them protection. While in smaller outcrops there may have been some direct impact of the fires, deep crevices in rocky escarpment and outcrops appear to have acted as vital refuges for the geckos. Continued monitoring of this species will be required to determine whether the longer-term, indirect effects of the fires affect population persistence.

Fig. 14.4. Burnt habitat of Kate's leaf-tailed gecko. (Photo: Matt Greenlees)

In February 2020, the Australian Government released a rapid assessment of the impacts of the 2019–20 wildfires, which included a list of priority reptile species in need of urgent reconnaissance surveys and management interventions (Legge *et al*. 2020). This rapid assessment considered the proportion of a species' range that overlapped with fire (divided into overlap categories) and species' national conservation status (i.e. EPBC Act or IUCN status). Species in the highest fire overlap categories (i.e. 50–80% or > 80%) that were listed as threatened (under either the EPBC Act or IUCN) were ranked most in need of attention, while non-threatened species with high overlap were included if their traits or vulnerabilities suggested acute, negative responses to fire and/or the immediate post-fire landscape (Legge *et al.* 2020). Finally, species were added if they had very narrow distributions within or in very close proximity to the firegrounds, regardless of their traits (e.g. Kate's leaf-tailed gecko); state agencies made a specific case for their inclusion based on expert knowledge; or if taxonomic considerations suggested possible effects on significant ecological units. The priority species were typically narrowly distributed with relatively high fire overlap (Figs 14.2, 14.3).

The rapid assessment used maps of nationally threatened species held by the Department of Agriculture, Water and Environment (DAWE), and otherwise relied on IUCN range maps. A subsequent project (Legge *et al.* in press) refined these maps for several species using species distribution models (SDMs), and resulted in some marked changes in the estimated fire overlap. For instance, overlap for the Blue Mountains water skink (*Eulamprus leuraensis*) – a species of great concern given its narrow distribution, threatened status (Endangered under IUCN) and declining population trajectory (Chapple *et al.* 2019) – increased from two-thirds using IUCN maps to 81% using SDMs. The changes in overlap in some instances moved species from one overlap category into another. For instance, the mustard-bellied snake (*Drysdalia rhodogaster*) moved from the 30–50% overlap category when using IUCN maps to the 50–80% category when using SDMs, while an increase in fire overlap for the Blue Mountains water skink moved it from the second highest (50–80%) to the highest (> 80%) category. These changes, while relatively rare, would have influenced how species were ranked during the rapid prioritisation (Legge *et al.* 2020), highlighting the importance of high-quality distribution data to allow overlap to be accurately measured.

Fire severity was not considered during the initial rapid assessment because national fire severity maps were not available, but DAWE later developed a nation-wide fire severity map (DAWE 2020b). Assessing the extent of overlap between species' ranges and fire severity classes added nuance to the emerging picture of how species were likely affected by the wildfires. For instance, although the entire range of Kate's leaf-tailed gecko burnt, more than half burnt at low severity. Similarly, the narrowly distributed Kaputar rock skink (*Egernia roomi*) had substantial fire overlap (66%), but 95% of areas within the fire boundary burnt at low severity. These species may not be as severely affected as initially feared.

Assessing species and within species diversity

Assessment of the impact of fires on individual species can be challenging when overarching questions about taxonomy are unresolved. The 2019–20 wildfires impacted wet forests that are naturally fragmented in eastern Australia, and the distributions of many of the reptile species endemic to these forests are also naturally fragmented (Rosauer *et al.* 2015). Naturally fragmented habitats can lead to many cryptic species that are not yet recognised by science nor conservation. Recognising and naming these species is challenging – cryptic species often require genetic data to identify species status, and vouchers are needed for species description. Below the species level, identifying and protecting within-species genetic diversity is important for managing threatened species. Highly fragmented species will have populations whose genetic distinctiveness should be preserved to ensure the longevity of the species, as genetic diversity contributes to prevention of inbreeding depression, is important in developing captive populations, and is essential to enabling species to adapt to change (reviewed in Pierson *et al.* 2016).

Genetic data were unavailable to assess the taxonomic status and within-species diversity for many of the priority squamate species. A review of the 14 priority squamates for which landscape genetic data did exist (Catullo *et al*. 2021; Catullo and Moritz 2020) identified three that included undescribed or candidate species. When unrecognised species are included in assessments of fire impact, it can completely shift estimated fire overlap. Splitting species inherently reduces range size, meaning the estimated impact can be greatly increased for one species and reduced, even to zero, for other species. An example of shifting impacts is seen in the *Eulamprus kosciuskoi/leuraensis* species complex, which is distributed in three disjunct locations (Fig. 14.5). Genetic assessment of this complex (Pepper *et al*. 2018) identified that the two geographically discrete populations of *E. kosciuskoi* were not monophyletic and hence were likely distinct species. All three lineages within the species complex were distributed almost entirely within burnt areas and failure to recognise these as distinct would have resulted in an underestimation of fire impacts on both species currently within *E. kosciuskoi*. Assessments of within-species diversity across the 14 species identified 19 evolutionarily significant units and more than 18 management units, indicating that reptile species within the fire-affected regions were highly fragmented with distinct

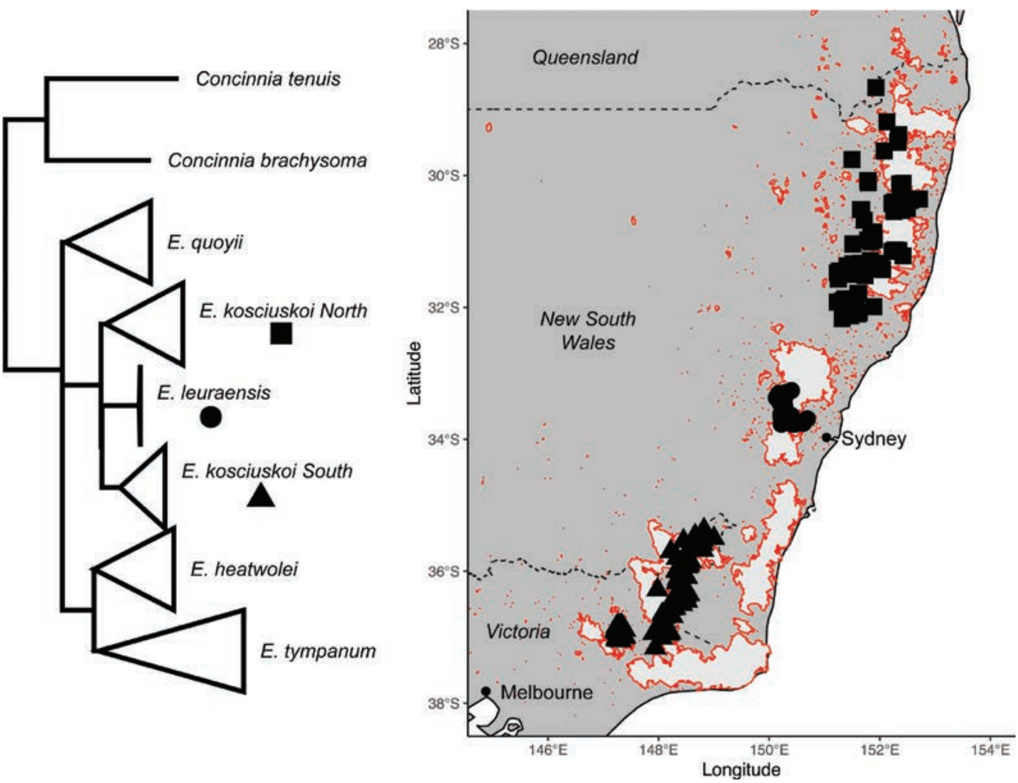

Fig. 14.5. Phylogenetic tree of *Eulamprus* taxa (modified from Pepper *et al*. 2018), which identified species-level divergence across each of the three geographically distinct clades in the *E. kosciuskoi/leuraensis* complex. The distribution of clades (shapes) is shown relative to the 2019–20 wildfires (pale areas outlined in red), which shows that each clade is independently fire impacted and requires assessment and management of impacts.

populations that require careful and independent overlap assessment and management planning.

Beyond fire overlap: engaging experts

Quantifying overlap between the 2019–20 wildfires and species ranges, once the taxonomic units are defined, is relatively straightforward, but the obvious question is: how have the fires impacted populations on the ground? Answering this question is complicated by the paucity of information on the natural history of squamate reptiles, a lack of research on the responses of lizards and snakes to fire (outlined above), and – with some notable exceptions (Box 14.2, Fig. 14.6) – long-term monitoring of squamate populations within the fire-affected regions. Monitoring programs are lacking even for Australia's most imperilled reptiles: nearly 40% of Australia's threatened reptiles lack any form of population monitoring (Woinarski 2018). Threatened reptile populations are monitored the least of all terrestrial vertebrate groups (Scheele *et al*. 2019).

Box 14.2. Broad-headed snake

Broad-headed snakes (*Hoplocephalus bungaroides*) are small (< 90 cm snout–vent length), live-bearing, venomous elapid snakes, which are listed as Vulnerable under the EPBC Act. They have a relatively small geographical distribution – within a ~250 km radius of Sydney – and require intact sandstone rock outcrops to persist (Fig. 14.6). During cooler months (May–October), broad-headed snakes occupy the edge of exposed sandstone plateau where they shelter under small, exposed rocks. However,

Fig. 14.6. Broad-headed snake in its sandstone habitat. (Photo: Chris Jolly)

during the warmer months (November–April), they leave the outcrops for the shelter of old-growth eucalypt forests where they shelter in tree hollows (Webb and Shine 1998). Adult snakes are most vulnerable to wildfires during this period (Webb *et al.* 2021). Approximately 72% of their geographical range burnt during the 2019–20 wildfires (Figs 14.2, 14.3). A long-term (30 years) study of a population in Morton National Park provides an insight into the effects of the 2019–20 wildfires on this species. The region was burnt by high-intensity fires in November and December 2002 (the Touga Fire) and in January and February 2020 (the Morton Fire). Estimates of abundance showed that the study population declined by 34% and 26% after the Touga and Morton fires, respectively (Webb *et al.* 2021). The population recovered 1 year after the Touga Fire, but no population recovery was apparent 1 year following the Morton Fire (Webb *et al.* 2021).

The broad-headed snake offers an illuminating case study on the importance of context when assessing the impacts of wildfire on threatened species. The major threats to broad-headed snakes are the removal of natural rocks for the landscaping industry, and removal of snakes for the illegal pet trade. Rock removal results in a loss of thermally suitable shelter sites for broad-headed snakes and one of their major prey species, the velvet gecko (*Amalosia lesueurii*) (Shine *et al.* 1998). In the Morton National Park population, adult survival rates were 20% lower in years when humans had overturned rocks while searching for snakes, suggesting that snake collectors had removed snakes from the wild for private hobbyist collections. The snake's slow life history (maturity at 6 years), small litter size and infrequent reproduction (reproducing every second or third year) means that the removal of adult females can drive small populations extinct (Jolly *et al.* 2021). The population has declined by ~60% over 30 years, from 127 in 1992 to only 50 snakes in 2020. If one extrapolates to the entire study plateau, the total population currently sits at just 300 snakes, half the number that was reported in 2002 (Webb *et al.* 2002). This result highlights how declines wrought by wildfires need to be considered among other threatening processes. In the case of the broad-headed snake, poaching and bush rock removal pose far greater threats to the persistence of the Morton National Park population than do single wildfires. However, while stable populations of broad-headed snakes may recover from severe fire events, small declining populations may not, and increases in the frequency and intensity of wildfires could hasten local extinctions.

Given the scarcity of prior research and baseline monitoring for most species – and the time needed to assess impacts and recovery – alternative approaches are needed to estimate which species are most acutely affected by the fires. One means of temporarily filling this gap is expert elicitation. To assess the impacts of the 2019–20 fires on reptiles, a structured approach, known as the IDEA (Investigate, Discuss, Estimate, Aggregate) protocol (Hemming *et al.* 2018), was used to elicit knowledge. Experts identified the rainforest cool-skink (*Harrisoniascincus zia*), alpine she-oak skink (*Cyclodomorphus praealtus*), and long sun skink (*Lampropholis elongata*) as being most adversely affected by high severity fires. These species occupy quite distinct habitats – from alpine grasslands to rainforest. What they share is a tendency to shelter in or under flammable retreat sites, such as grass tussocks, leaf litter and logs. By contrast, some species were predicted to be relatively resistant to the immediate effects of fire, such as some leaf-tailed geckos (*Saltuarius* spp.) and the Kaputar rock skink, which make greater use of non-flammable shelters such as rock crevices.

Estimates of fire impacts were used to extrapolate the range-wide impacts of the 2019–20 wildfires on each species, while also considering each species' pre-fire population trajectory. The species predicted to suffer the largest population declines immediately after the wildfire included the Blue Mountains water skink (~25% decline) and the alpine she-oak skink (~20%), due to a combination of vulnerability to, and substantial overlap with, high severity fire. Despite experts predicting that the narrowly distributed Kate's leaf-tailed gecko would suffer less fire-induced mortality than many other species, it nonetheless ranked among the most impacted species due to its entire range being within the boundary of the wildfires.

Most species were predicted to undergo further declines between 1 week and 1 year after the wildfires, probably reflecting the harsh conditions typical of post-fire landscapes, such as reduced resources and increased predation risk. Projecting forward to 10 years or three generations post-fire, the Blue Mountains water skink and the alpine she-oak skink were still projected to have declined most substantially, with both predicted to decline by ~30%. In these taxa, the overall population size is predicted to be ~10% less than it would have been had the fires not occurred. Based on this analysis, Legge *et al.* (in press) suggested up to nine reptile species should have their conservation status assessed for potential listing as threatened, including the unlisted Kate's leaf-tailed gecko, the Kaputar skink and the long sun skink.

Future assessment and management implications

Future rapid assessments to large wildfires will also be heavily reliant on maps, but there is ample room for improvement in the kinds of maps that are used. First, the comparisons of IUCN range maps with more refined SDMs highlight the need for a national database of up-to-date species distribution maps, generated using high-quality, contemporary data, and vetted by experts with on-ground knowledge. Second, Australia urgently needs a national monitoring agency responsible for generating and cataloguing fire events across the country in a consistent manner (Bowman *et al*. 2020). Reliable, nation-wide maps of long-term fire histories would have allowed rapid assessments to incorporate not only the amount of a species' range affected by the 2019–20 wildfires but also the underlying fire history. Similarly, high-quality maps of other threats could aid in identifying important refuges while guiding management actions.

Woinarski (2018) described a vicious cycle that reinforces the inadequacy of Australia's reptile monitoring and conservation. A lack of monitoring data for reptiles results in fewer species with population data necessary to support their listing under the EPBC Act (e.g. rate of population decline). A lack of listing leads to a lack of investment in reptile monitoring and conservation, which perpetuates the cycle (Woinarski 2018). This cycle intersects with the rapid assessment described here in several ways. First, given that species' conservation status was a major component of the species ranking (Legge *et al.* 2022), imperilled species that are not formally listed may have been overlooked. Second, a lack of survey and monitoring effort means that the distributional limits of many species remain uncertain, complicating the calculation of overlap measures. Third, a lack of investment in monitoring means we lack baseline data on the status of populations leading up to and following the 2019–20 wildfires. This is further compounded by a lack of studies on squamate responses to fire, particularly concerning aspects of the fire regime beyond the most recent fire event (outlined above). Hence, future investment in monitoring Australia's squamate fauna is fundamental to their conservation, particularly given the increasing frequency of large-scale disturbance events. There is also a need to understand the effectiveness of post-fire interventions aimed at limiting decline or hastening recovery.

In many instances, it may be most effective to address co-occurring threats (Box 14.2). With these threats removed, species may be more resilient to large wildfires.

Conclusion

This chapter has considered the impacts of the unprecedented 2019–20 wildfires on Australia's unique squamate fauna. While the wildfires burnt the habitats of hundreds of squamate species, and over 60 species have ranges that overlapped with the fires by > 10%, our systematic review revealed how little research has been undertaken that can help us predict the outcomes for squamate populations on the ground. This knowledge gap was filled using structured expert elicitation, but empirical data are needed; this will involve a step change in investment in squamate monitoring, research and conservation. Management interventions that will aid in the recovery of squamates will involve addressing key threats to squamates, including invasive predators, feral herbivores, unsustainable development, land clearing, and, notably, inappropriate fire regimes.

We have identified several obstacles that need to be addressed to improve upon further rapid assessments in the wake of future megafires (see 'Recommendations').

Recommendations

- Research that documents the immediate and indirect effects of fire on Australian squamate reptiles, including multiple aspects of the fire regime, is urgently needed. This will require funding for new projects and better use of existing data.
- Broad-scale, population-level genetic sampling to clarify taxonomic uncertainty and within-species genetic diversity in Australian reptiles, to facilitate more accurate assessments of fire impacts and improve success of recovery efforts, such as translocations, is needed.
- Substantial investment in statistically robust and powerful monitoring for lizard and snake populations is needed to document trajectories and to assess how species are affected by fire events and regimes, as well as other potential threats.
- Systematic curation of vetted geographical records of species observations is required to refine understanding of the distributions of Australian reptile species, including the development of species distribution models where possible.
- Drawing upon enhanced monitoring, species assessments and conservation advice must be current for Australian reptile species, to help break the cycle of underfunding reptile conservation.
- Further investment in the conservation of Australia's threatened reptile species, including funding for conservation interventions and threat abatement, is needed.

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