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Impacts of the 2019–20 wildfires on Australian invertebrates

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Summary

Context and challenges

- There are far more species of invertebrates than any other component of Australia's biodiversity, and many have highly localised ranges: hence, it is likely that much of the biodiversity loss in the 2019–20 wildfires was experienced by invertebrate species.
- However, profound knowledge gaps render it especially challenging to assess the impacts of the 2019–20 wildfires on invertebrate species, and to direct and prioritise recovery responses.
- Invertebrate species also have low public profiles and low priority in conservation management efforts, so their losses in these wildfires have been overshadowed by those of more iconic vertebrate species.

Main findings

- Based on spatial analysis of distributional records, we found that for the 2019–20 wildfires:
  - At least part of the range of 13 581 invertebrate species was burnt.
  - Three hundred and eighty two species had their entire range burnt. However, all of these were species with only one or two records each, so their fire overlap values are of low confidence, because their actual ranges are so poorly resolved.
  - The numbers of fire-affected invertebrate species are far higher than comparable tallies for vertebrate species.
- From analysis of fire overlap and species' likely susceptibility to fire, we conclude that at least 60 invertebrate species are likely to have become eligible for listing as threatened because of the 2019–20 wildfires; for context, this is a

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similar tally to the total number of terrestrial invertebrate species currently listed nationally as threatened (63 species).

- Although extinction is difficult to prove, it is highly likely that the *Banksia montana* mealybug (*Pseudococcus markharveyi*) went extinct because of the 2019–20 fires. It is plausible that the number of fire-related extinctions is much higher, but there have been few post-fire searches that would allow extinction to be corroborated or refuted.
- Many species from ancient lineages are likely to have been particularly impacted by the 2019–20 wildfires.
- The most important recovery management action for fire-affected invertebrate species is to attempt to reduce the likelihood of future comparable wildfires, to mitigate impacts of such fires if they do occur, and to create a patchwork mosaic of fire ages, including areas of longer unburnt habitat.

Introduction

There are ~320 000 invertebrate species in Australia (Chapman 2009) – ~40 times the number of vertebrate species and ~12 times the number of plant species. Many Australian invertebrate species have highly restricted distributions ('short range endemics') (Harvey *et al*. 2011), rendering such species particularly at risk from acute threats. Given their diversity and restricted nature, it is probable that the majority of the biodiversity impact of the extensive 2019–20 Australian wildfires was experienced by invertebrate species (Hyman *et al*. 2020). Yet the public profile of, and responses to, biodiversity losses in the wildfires focused predominantly on vertebrate species, particularly iconic animals such as the koala (*Phascolarctos cinereus*) (e.g. Mo *et al*. 2021; Parrott *et al*. 2021). This taxonomic mismatch of impact and response is consistent with the disproportionately small representation of invertebrates on threatened species lists, and in conservation policy and management in Australia (Braby 2018; Taylor *et al*. 2018) and globally (Régnier *et al*. 2015).

In this chapter, we report on the impacts of the 2019–20 wildfires on Australian invertebrate species. The material presented here is based in part on more detailed reporting in Marsh *et al*. (2021) and Marsh *et al*. (in press). Note that Chapter 6 describes in more detail the impacts of the wildfires on aquatic invertebrates, especially spiny crayfish (*Euastacus* species).

There are long-standing impediments to the conservation of Australian invertebrates, largely relating to major shortcomings in knowledge (Taylor *et al*. 2018), and these challenges also constrain assessments of the impacts of the 2019–20 wildfires (see also Chapter 32). The majority of invertebrate species in Australia are not yet described (Austin *et al*. 2004; Chapman 2009), so assessments of fire impacts on described species substantially underestimate the actual number of fire-affected invertebrate species. For many of the described invertebrate species, there are very few records. For example, our detailed analysis (Marsh *et al*. 2021) collated, across all readily available distributional databases, a total of 342 534 records of 45 529 invertebrate species; but of these species, 31% had only one record and 14% had only two records in these collated databases and, for such species, estimates of fire impact have low confidence.

For most invertebrate species, there are no monitoring programs (Legge *et al*. 2018): this means that it is almost impossible to assess population losses due to these wildfires. There are also disproportionately few Australian invertebrate species listed as threatened

(Walsh *et al*. 2013), and few subject to conservation management programs. As a consequence, imperilled invertebrate species were generally not prioritised for protection in operational actions during the 2019–20 wildfires, and there is little knowledge of management actions that may support post-fire recovery of fire-affected invertebrates.

Relative to the amount of knowledge derived from research on vertebrates and plants, there have been few studies of the responses of Australian invertebrate species to fires (Saunders *et al*. 2021). For example, a review of the responses to fire of Australian biodiversity noted that:

> *the patterns of fire responses exhibited by invertebrates are … even more difficult to detect than those … for vertebrates and plants … invertebrates deserve far more attention than they have received to date in fire ecology … given the less-than-ideal state of the data relating to fire-response patterns exhibited by invertebrates, it is not surprising that our understanding … is poor. (Whelan et al. 2002, pp. 98, 111)*

Furthermore, most of this limited knowledge of the impacts of fire on invertebrates relates to mild fires rather than fires of the severity of the 2019–20 wildfires (Friend 1994). Of these few studies, many also reported on the fire responses of higher taxonomic groupings of invertebrates (families or orders) rather than individual species, thereby potentially obscuring the impacts on that subset of species that are fire sensitive (Majer *et al*. 1997).

In part because such studies typically report the persistence of some invertebrate groups after (mild) fires, there is now something of an established paradigm that invertebrates are relatively impervious to fires. For example, Bradstock (2008, p. 812) reported:

> *Most invertebrate groups are little affected by fires, principally because individuals in varied life cycle phases are able to avoid lethal heat via shelter in soils, tree stems and rocks. The abundance and density of differing invertebrate groups typically display rapid resilience after fires of varied type and intensity.*

Although this statement may be valid for some groups, it is unlikely to represent invertebrates that are restricted to fire sensitive habitats, have small ranges or population sizes, occur in microhabitats that provide little protection from fire, or have life history characteristics (e.g. low reproductive output, limited dispersal capability) that constrain recruitment. For species with such characteristics, much of the population may be killed during fire and recovery may be challenging. In this chapter, we focus on such species, identifying those whose conservation status and outlook was most detrimentally affected by the 2019–20 wildfires, and hence are most in need of targeted management that supports recovery.

Our assessment focuses mainly on the consequences of the 2019–20 wildfires on individual invertebrate species, but such a focus should also be more broadly contextualised. One such context relates to fire regimes, and the consequences more broadly of repeated fires. In many cases, fire impacts may be magnified (and recovery thwarted) by short intervals between successive fires, or a history of fires that each burn part of a habitat but collectively burn most or all of it (Moir 2021). Any presumption that invertebrates may be resilient to fires is unlikely to apply if regimes change to more frequent and severe fires.

Furthermore, the impacts of the 2019–20 wildfires should not be considered in isolation, because they may compound or be compounded by other threats that collectively

may imperil a species far more than the influence of any factor alone. For example, the Bogong moth (*Agrotis infusa*) was historically super-abundant (with billions of individuals), but has declined dramatically in recent years, due to land-use changes, drought and other factors (Green *et al*. 2021). The 2019–20 wildfires added incrementally to this pattern of decline (Green *et al*. 2021).

In a broader context, the impact of the fires on invertebrates will have far-reaching consequences beyond the invertebrates themselves: the fires will affect the pivotal ecological functions that invertebrates provide (Waldbauer 2004). The 2019–20 wildfires caused marked reductions in the population size, biomass and diversity of many invertebrates over extensive areas, and such losses are likely to cause long-lasting ecological degradation and complex repercussions for ecosystems. Furthermore, some invertebrate species have cultural significance: for example, the Bogong moth is not only a keystone species (Braby *et al*. 2021), but has also long been important to Indigenous Australians for ceremony and sustenance (Stephenson *et al*. 2020).

To assess the impacts of the 2019–20 wildfires on Australian invertebrates, we collated species' distributional data from many sources (mostly the Atlas of Living Australia) and created range polygons for all species with at least three records. We then overlaid – for every species – the individual point records and polygons with maps that categorised fire severity (Department of Agriculture Water and the Environment 2020) to calculate 'fire overlap' – the proportions both of its records and of its modelled distribution that was burnt (Marsh *et al*. 2021). Our analysis was restricted to those regions of eastern and southern Australia that experienced exceptional fire events in 2019–20 (the 'Preliminary Analysis Area' (PAA): see Chapter 1).

Quantifying fire overlap is relatively straightforward, but assessment of impact is more challenging. To complement our assessments of fire overlap, we developed and applied a trait database for invertebrate species that comprised information on life history characteristics, threats and management needs. We then used the trait database to identify species likely to have experienced the most loss in the 2019–20 fires. Marsh *et al*. (2021) present these methods and analyses in detail. Ideally, this approach for estimating fire impact should be tested by post-fire surveys to corroborate the predicted extent of population loss; however, there has been very limited post-fire sampling for most invertebrate groups (but see Box 11.1 for one example).

Box 11.1. Kangaroo Island assassin spider

The Kangaroo Island assassin spider (*Zephyrarchaea austini*) (Fig. 11.1) is a small spider (< 3 mm long), whose known range is restricted to western Kangaroo Island. At the time of the 2019–20 fires, it was only known from a single conservation reserve (Western River Wilderness Protection Area). The species lives in a microhabitat (elevated leaf litter suspended among low-lying vegetation) that is highly flammable, even in low-intensity fire, and offers little shelter from fire. The entirety of Western River Wilderness Protection Area burnt in severe wildfires in 2019, with the exception of a small section that had been subject to a fuel reduction burn in 2015. Surveys of this latter area found that, despite 6 years passing post-burn, the elevated leaf litter layer had not yet accumulated, ensuring that the habitat

was not suitable for the assassin spider. This example highlights the lag time required before burnt habitat will be suitable for such species and also the challenges in balancing fire management actions and conservation, especially for species susceptible to even low-intensity fires. Happily, after many fruitless months of intensive post-fire searches of unburnt habitat in and near the known range, a single individual was located in September 2021 (J. Marsh, *pers. obs.*), providing some hope for the future of the species (see also Chapter 34).

Fig. 11.1. There is no known photograph of a live Kangaroo Island assassin spider. Here, a related species, the eastern massif assassin spider (*Zephyrarchaea robinsi*). (Photo: M. Harvey, © Western Australian Museum)

Findings

We collated distributional data (342 534 records) for 45 528 Australian invertebrate species, of which 32 163 species occurred in the PAA, with a total of 238 633 records. We found that the 2019–20 wildfires burnt at least part of the range of 13 581 of these species. For 787 species, at least 50% of their range was burnt in fires of any severity and/or at least 30% of their range was burnt by fires of high severity. For 382 species, *all* of the known range was burnt, although we note that this tally comprised only species with one or two occurrence records each, so fire overlap values are of low confidence. These results corroborate and extend to national scale an earlier finding, for a subset of taxonomic groups of invertebrates at more regional scale (New South Wales), that all of the known range of many invertebrate species was burnt in the 2019–20 wildfires (Hyman *et al.* 2020).

These tallies are substantial underestimates of the actual number of invertebrate species affected, as our analysis was mostly restricted to described species, which comprise only about one-third of the estimated number of Australian invertebrates (Chapman 2009), and because we could find no acceptable records (e.g. of sufficient locational precision) for many described species known to occur in the PAA.

The numbers of invertebrate species impacted by fire are far higher than the comparable tallies for vertebrate species (Table 11.1), with invertebrate species contributing 98% of the animal species with at least 90% distributional overlap with the 2019–20 wildfires. For example, we found that 2186 invertebrate species had higher proportions of their distributions burnt than the koala (17%), an iconic vertebrate species accorded pre-eminent public profile as a casualty of the 2019–20 fires, and a major focus of the conservation response (Parrott *et al.* 2021). Although the values are not readily accessible, we doubt that the total recovery investment spread across these 2000+ invertebrate species more fire-affected than the koala would be within an order of magnitude of the effort directed towards the koala (Marsh *et al.* in press).

Fire overlap is not synonymous with fire impact. Some invertebrate species occurring in burnt areas may nonetheless have experienced little immediate mortality because the

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Table 11.1. The number of species of invertebrate and vertebrate taxa with extensive overlap with the 2019–20 wildfires.

Tallies in brackets for invertebrates exclude those species with only one or two records in our analysis. Data sourced from Marsh *et al.* (2021).

% overlap with fire	No. of species					
	Invertebrates	Fish	Frogs	Reptiles	Birds	Mammals
100%	382 (0)	4	0	0	0	0
90–99.9%	6 (6)	1	1	1	0	1
80–89.9%	25 (25)	0	1	1	0	1
70–79.9%	26 (26)	0	3	1	0	1
60–69.9%	43 (43)	0	3	1	17	1
50–59.9%	305 (103)	4	8	1	4	5
Total 50+	**787 (203)**	**9**	**16**	**5**	**21**	**9**

entire population or particular life stages are sheltered from fire – for example, by living deep enough underground. However, fire may affect even such species if the post-fire environment offers fewer resources, higher rates of predation or more extreme microclimates.

For the invertebrate species with at least 50% overlap with fire or at least 30% overlap with severe fire (defined in the fire mapping as canopy scorched or consumed), we compiled a database of life history, ecological and other traits related to fire susceptibility. In our trait database we also included 19 expert-nominated species for which there were sufficient private distributional data and a further nine threatened species with 30–50% overlap with all fires. Combining trait information with fire overlap data, we concluded that at least 60 of these invertebrate species were likely to have suffered at least 30% reduction of their population due to the 2019–20 fires, and hence were likely to be now eligible for, and have sufficient information to justify, listing as threatened (see Supplementary Table S11 online at doi:10.6084/m9.figshare.20132213). If such species were indeed to be listed nationally as threatened, it would result in an almost 100% increase in the number of terrestrial invertebrate species currently listed nationally as threatened (63 species).

The actual number of invertebrate species that are now imperilled because of the 2019–20 wildfires is likely to be far more than 60, but information shortcomings constrain listing assessments for many species. For example, some species were represented in our analysis by only one or two records, while for others information on traits was unavailable. For such species, particularly where the fire impact was suspected to be severe, filling information deficiencies should be prioritised, such as through post-fire surveys to better assess the extent of population loss and to safeguard any detected surviving populations.

Invertebrates across most taxonomic groups were affected by the 2019–20 wildfires. Impacts were especially pronounced for groups with (1) many short-range endemic species, (2) many species occurring in habitats that are fire sensitive and (3) many species occurring in micro-habitats that offer little protection from fire. For some groups, such as millipedes, land snails, flightless ground beetles and a few spider families, many of their species fit in all three of these categories. Note also that many of these groups are of great antiquity (Rix and Harvey 2012), and the increasing severity and incidence of wildfire are likely to cause ongoing loss and retreat of these old lineages, as areas long offering them protection from fire become increasingly less secure.

The 2019–20 wildfires are likely to have caused the extinctions of some invertebrate species. However, extinction is difficult to prove, especially so for species that are poorly

known (e.g. those for which locational information was meagre before the fire) and hard to detect. Nonetheless, there is compelling evidence that the 2019–20 wildfires caused the extinction of at least one species, the *Banksia montana* mealybug (*Pseudococcus markharveyi*) (Moir 2021) (see Box 11.2).

Box 11.2. *Banksia montana* mealybug

The *Banksia montana* mealybug is, or was, a tiny (1–3 mm) true bug of underwhelming charisma (Fig. 11.2). It had some characteristics that should have given it some conservation security. From not long after its discovery (in 2007) and description (in 2013), it has been listed as Critically Endangered at global, national and state (Western Australia) levels, nominally affording it some conservation profile, protection and action. Its ecology was reasonably well known and its distribution precisely known due to targeted surveys. The mealybug's entire range was within a high-profile conservation reserve (Stirling Range National Park) with a well-established fire management plan. Much intensive conservation management was directed towards its host plant species (including translocations, application of phosphite to mitigate dieback and caging to reduce pressure from mammalian herbivores). Fire was a recognised threat to the species and, as a consequence, its known locations were delineated in fire plans and highlighted for protection during fire operations. Some conservation efforts had been specifically implemented for the mealybug to try to

Fig. 11.2. *Banksia montana* mealybug (square and inset) within foliage of its host plant. (Photos: © Melinda Moir)

reduce its extinction risk, such as through attempted translocations, but unfortunately these resulted in multiple failures, in part due to predators and parasitoids (Threatened Species Scientific Committee 2018).

However, the mealybug also had characteristics that rendered it especially susceptible. It was entirely dependent on a single host plant species, *Banksia montana*, that also happened to be extremely rare, highly localised and fire sensitive; it occurred only on old (at least 9 and up to 30 years) individual plants. It also had very limited dispersal ability, so could not readily recolonise burnt areas from unburnt patches. Indeed, it could not disperse unless host plants had interlocking foliage, with the bugs walking over 'bridges' of crossed branches. This adaptation was probably suitable when the mountain ridges were covered in a dense tall heath featuring abundant *Banksia montana*, but the history of fires meant that such conditions no longer exist. These imperilling characteristics ended up outweighing the conservation efforts. By 2012, it was known to occur in only two small sites, 7 km apart. In 2018, a control burn, designed to reduce the likelihood of wildfire, burnt one of these sites, destroying the population of mealybugs and rendering the host plants there unsuitable for many years. Following that fire, the entire mealybug population occurred only on six plants present at one site. From 26 December 2019, a series of severe fires that burnt 40 000 ha of the national park killed all of these plants and, as a consequence, the mealybug is now likely to be extinct (Moir 2021).

This case shows the devastating impact of a single fire event, but also illustrates the cumulative impacts of successive fires (iteratively depleting populations) and the importance of fire regimes generally. It also provides the hard lesson that conservation objectives for fire management – in this case a recommended interval between successive fires of at least 18 years, and exclusion of fire from the sole known population – may be challenging or impossible to achieve, even in landscapes largely devoted to conservation.

The likely extinctions, and the extent of population losses for so many other invertebrate species, indicate that the 2019–20 wildfires had a catastrophic impact on the Australian invertebrate fauna. For some of the extant but severely fire-affected species, recovery may take many years and may never be realised if comparable wildfires recur in the near future. For other fire-affected species recovery may be possible, but it will require targeted and effective management investment at a scale that vastly exceeds the limited effort that has typically been devoted to invertebrate conservation in Australia.

We applied information from our trait database to identify the main threats to, and thus indicate the likely management needs of, the fire-affected invertebrate species (Marsh *et al*. 2021). For most species, the most significant ongoing threat is the likely increased frequency of severe wildfire, and the action most needed to support recovery and to limit future losses is targeted fire management. In many cases this involves excluding fire from sites holding surviving populations and attempting to prevent recurrence of comparable severe fires in areas burnt in the 2019–20 wildfires.

Given the major knowledge gaps that currently constrain conservation of Australian invertebrates, monitoring programs should be implemented for fire-affected invertebrate species. Such monitoring can help document the pace and extent of recovery, assess the effectiveness of management actions (see Box 11.3), and provide a more robust baseline from which to assess the impacts of future fire events.

Box 11.3. Green carpenter bee

The green carpenter bee (*Xylocopa aeratus*) (Fig. 11.3) provides a contrast to the two other case study species in that historically it was widespread, from northern New South Wales to South Australia. However, due to the compounding impacts of habitat loss and fragmentation, and inappropriate fire regimes, many subpopulations have been extirpated and it is now considered regionally extinct in Victoria. In South Australia, this large and spectacular native bee survives solely on Kangaroo Island, in old-growth (> 35 years old, but typically 50–90 years old) heathlands. This habitat association is largely because it is reliant on the soft wood of large dead trunks of *Banksia* spp. and dried flower stalks of grass-trees (*Xanthorrhoea* spp.) for nesting substrates. For the Kangaroo Island subpopulation, extensive fires in 2007 severely reduced old-growth habitat, and the fires of 2019–20 burnt ~95% of the remaining habitat. The Kangaroo Island bees now survive precariously only in some small unburnt patches. Every such severe fire locally annihilates bees and destroys old-growth nesting substrate, which takes at least 35 years to recover, and such subpopulation losses cumulatively increase the overall risk of extinction. Researchers have trialled, with some success, artificial breeding sites to help maintain and recover bee subpopulations, but the most critical management requirement is to seek to ensure that habitat remains unburnt for many decades – a formidable challenge (Hogendoorn *et al.* 2021).

Fig. 11.3. Green carpenter bee (*Xylocopa aeratus*) from Kangaroo Island, showing female (above) and male (below). (Photo: Dr Richard V. Glatz)

Our analysis focused on the impacts of the 2019–20 wildfires on individual invertebrate species; however, assessment of the impacts and consequent management needs of thousands of invertebrate species poses formidable challenges, and the history of conservation efforts for Australian invertebrates does not provide much reassurance that such challenge will be embraced. Furthermore, a conservation response focused solely on the needs of individual species recognised to be fire-affected does little for the conservation of the most poorly known species (including those that have not yet been described) or for ecosystem functioning. A complementary approach that may be more strategic is to identify sites in the landscape that are of exceptional significance for the conservation of invertebrates more broadly, and to factor the protection of such sites into management planning and operations. Given the propensity of invertebrates in some taxonomic groups to be characterised by very small ranges (Harvey 2002), this planning and protective management is especially relevant for sites that contain many co-occurring, short-range endemic species (centres of endemism). Exceptionally many species may be safeguarded, or lost, in these key locations: they are 'irreplaceable sites' (*sensu* Pressey *et al.* 1994) for

conservation. To date, few such key sites have been identified for Australian invertebrates (Moir *et al*. 2009; Barrett and Yates 2015). A more comprehensive systematic attempt to identify and circumscribe such sites, recognise these as key assets, and then include them in fire planning and operations should help to increase protection for many imperilled invertebrate species.

Conclusion

The 2019–20 wildfires had a devastating impact on many Australian invertebrate species. Some of these losses are unrecoverable, and reductions in population size for many invertebrates are likely to cause long-lasting ecological detriment. Recovery for many species will require targeted investment, at a scale far more substantial than the desultory efforts typically allocated to invertebrate conservation in Australia to date. The most important ongoing management action is to reduce the likelihood of future comparable wildfire. However, as illustrated in the case studies, the achievement of such an objective will be challenging. The fire management objective is also unlikely to be realised unless the root cause of such wildfires – climate change – is controlled effectively. Without such control, catastrophic wildfires will recur, and the Australian invertebrate fauna, including some lineages of great antiquity, will continue to be diminished.

Recommendations

- At least 60 invertebrate species for which there is sufficient evidence of severe impacts due to the 2019–20 wildfires should be assessed for national listing as threatened.
- Surveys should be undertaken for these species, and other more poorly known fire-affected species, to allow for robust assessments of population loss, and to identify important populations remaining after fire.
- Targeted management to support the recovery of fire-affected invertebrates must be identified in recovery plans, conservation advices and regional fire management plans, and implemented, with the scale of investment substantially increased from the meagre levels characterising previous conservation efforts for Australian invertebrates.
- The main priority for such management should be to reduce the likelihood of future comparable wildfires, and to maintain areas of long-unburnt habitat.
- Monitoring programs for fire-affected invertebrate species should be implemented to chart recovery, assess and refine management effectiveness, and provide a more robust baseline from which impacts of future fires can be measured.
- Important sites for the conservation of invertebrates (e.g. centres of endemism) should be identified and their protection mandated in policy and legislation (e.g as critical habitat). They should be recognised as priorities for protection in fire management plans and operations.
- Major knowledge gaps that constrained assessments of the impacts of the 2019–20 wildfires on the Australian invertebrate fauna should be filled. There is a need for better consolidation of distributional records, taxonomic resolution of poorly known groups, more targeted ecological studies (particularly of responses to fire, and to define preferred fire regimes), assessment of other threats, and development and maintenance of a database of species' traits related to fire susceptibility.
- Increased effort should be directed towards management of other key threats, to increase their resilience under a future marked by increased likelihood of wildfire.

- Raising the profile of invertebrate species at risk is required to elicit more public support and resourcing for their conservation. Such action should aim to encompass the suite of imperilled invertebrate groups rather than reinforcing bias towards those groups of most public appeal.
- The disproportionately low representation of invertebrates in threatened species lists and in conservation investment urgently needs to be rectified.
- More effective and urgent commitments to reducing greenhouse gas emissions are needed, for otherwise future fire regimes are likely to exert even more significant impacts on Australian invertebrates, with diminishing prospects of recovery.

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