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National **Environmental Science** Programme

Estimates of the impacts of the 2019–20 fires on populations of native animal species

Legge, S., Woinarski, J. C. Z., Garnett, S. T., Geyle, H., Lintermans, M., Nimmo, D. G., Rumpff, L., Scheele, B. C., Southwell, D. G., Ward, M., Whiterod, N. S., Ahyong, S.T., Blackmore, C.J., Bower, D.S., Brizuela-Torres, D., Burbidge, A. H., Burns, P.A., Butler, G., Catullo, R., Dickman, C. R., Doyle, K., Ehmke, G., Ensbey, M., Ferris, J., Fisher, D., Gallagher, R., Gillespie, G.R., Greenlees, M. J., Hayward-Brown, B., Hohnen, R., Hoskin, C.J., Hunter, D., Jolly, C., Kennard, M., King, A., Kuchinke, D., Law, B., Lawler, I., Lawler, S., Loyn, R., Lunney, D., Lyon, J., MacHunter, J., Mahony, M., Mahony, S., McCormack, R.B., Melville, J., Menkhorst, P., Michael, D., Mitchell, N., Mulder, E., Newell, D., Pearce, L., Raadik, T.A., Rowley, J., Sitters, H., Spencer, R., Valavi, R., West, M., Wilkinson, D.P., Zukowski, S.

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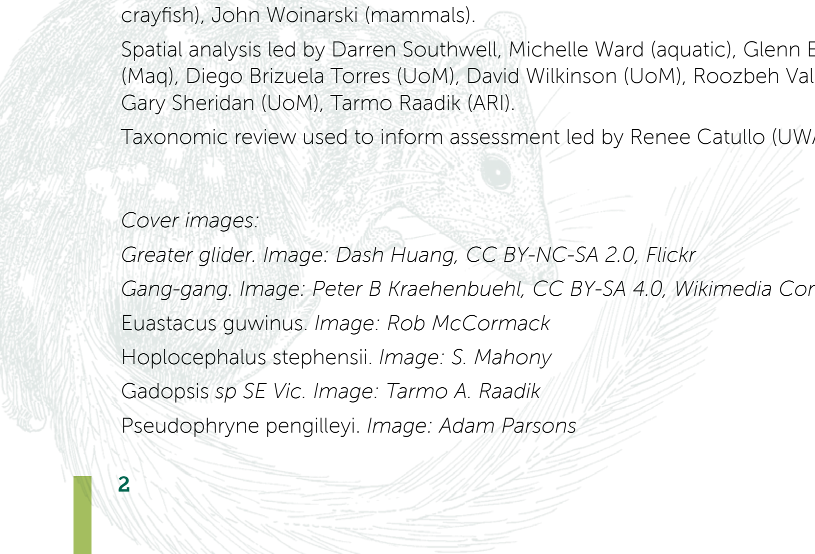

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Summary

Context

Severe drought leading up to spring in 2019 precipitated an extreme fire season in southern and eastern Australia. Over 104,000 km^2 (including > 20% of the forest biome) burnt between mid-2019 and mid-2020, much of it severely. Thousands of species of plants and animals, and many dozens of ecological communities, had distributions that were substantially fire-impacted. Responding effectively to an unprecedented event of such scale and magnitude has been, and remains, a challenge. Careful prioritisation of effort helps to direct attention and investment to where it is most needed to prevent extinctions and support recovery.

Aim

This study aims to provide estimates of population loss and likely extent and timing of recovery for the Australian vertebrate taxa and spiny crayfish taxa that were most heavily impacted by the 2019–20 fires. This information can be used to identify those taxa for which management is most needed to prevent extinction and aid recovery, and for which conservation status assessments are most critical.

Methods

We focussed on native vertebrate and spiny crayfish taxa with distributions that overlapped the extent of the 2019–20 fires by at least 10% if listed as threatened, and at least 25% if not listed as threatened. We collated distribution data for these 288 taxa (240 species, across six taxonomic groups) by sourcing the best available range maps, and by constructing species distribution models from observation records collated from multiple sources. We estimated the proportion of each taxon's distribution affected by fires of varying severity by intersecting the distribution data with the Australian Google Earth Engine Burnt Area Map (AUS GEEBAM). To estimate the spatial overlap of fire on aquatic taxa, we intersected their distributions with a model that described the spatial extent of fire-related aquatic impacts. We created the aquatic impact extent model by adapting an existing erosion model to include information on fire extent and severity, and post-fire rainfall events.

We carried out a structured expert elicitation to predict the local population responses of 173 taxa (143 species, representing six taxonomic groups), when exposed to mild or severe fire, or to no fire. Experts estimated the proportional change in local population size of every taxon immediately after the fire (up to one week), one year later, and 10 years/three generations later (whichever is longer). Estimates included the most plausible proportional change in local population size, the lower and upper bounds and the confidence that the real value lay within those bounds. Confidence bounds were then standardised to 80%.

For each species, we multiplied the local population estimates at each timeframe with the proportion of the species' distribution exposed to each of the three fire states (unburnt, mild fire, severe fire), to estimate the overall proportional change in population size of each taxon immediately after the fire, then out to 1 year and then 10 years/three generations after the fire.

Results

Overlaps between species distributions and fire extent/aquatic impacts extent: Of 288 taxa included in the spatial analyses of fire impacts, 199 taxa had distributions that overlapped with fire (or with aquatic impacts) by at least 25%; 76 taxa had distributions that were at least 50% fire-affected; and 16 taxa had distributions that were at least 80% fire-affected. Birds had the largest number of taxa with at least 25% fire-affected distributions, due in part to a large number of fire-affected subspecies endemic to Kangaroo Island. Fish and spiny crayfish had relatively higher proportions of taxa with distributions that were mostly or all burnt (>80%). Across each animal group, taxa with smaller distributions were more prone to having large proportions of those distributions being affected by fire. Fish and spiny crayfish in the assessment had smaller distributions, on average, than animals in other groups, and this partly explains why more of them experienced high fire overlaps to their distributions.

Expert estimates of local population response to fire: Of the 173 taxa (from 143 species) included in the structured elicitation, the taxa with the largest predicted declines at a site exposed to severe fire were both subspecies of the Greater Glider *Petauroides volans*, with an immediate population loss of 85% (80% confidence, 69% to 94%). Of the top 20 taxa with the largest proportional local population losses immediately after fire, 14 were mammals, five were birds, and one was a reptile. The frog taxon with the greatest estimated local population loss, the Southern Corroboree Frog *Pseudophyrne corroboree*, ranked 60th of 173 taxa in the elicitation; the most affected spiny crayfish (*Euastacus* sp. 2) ranked 79th, and the most affected fish, *Galaxias rostratus*, ranked 88th. By one year after fire, the ordering of species had changed: nine mammal taxa (reduced from 14) and 11 bird taxa (increased from five) were in the top 20, and fish, crayfish and frog species were beginning to move up the rankings. By 10 years/three generations after fire, the top 20 taxa with the largest local population declines comprised nine mammal species, five frog, four fish, and two bird species. The rearrangement of taxa from one week, to 10 years/three generations after fire reflects variation among taxa in their predicted recovery trajectories post-fire. The results suggest mammals and birds experience the greatest immediate impacts from severe fire, at least out to one year after fire. By 10 years/three generations after fire, mammals are still the most heavily impacted group, birds seem more able to recover, but frogs and fish either fail to recover, or continue to decline potentially because of impediments to natural recolonization and the effects of other threats.

Overall population declines and recovery: Of the 173 taxa (from 143 species) in the elicitation, 45 taxa returned estimates for overall population decline of at least 25% at either one week or one year post-fire. Birds comprised the largest number of taxa (n = 14) with population declines of 25% or more, followed by spiny crayfish and mammals (both n = 10), then fish (n = 7), with frogs and reptiles having only two taxa each with overall population declines of 25% or more. By 10 years/three generations, only one of these 45 taxa was predicted to recover to pre-fire levels; the Kangaroo Island Glossy Black-Cockatoo, *Calyptoryhnchus lathami halmaturinus*, which is receiving intensive management support. Recovery was a plausible possibility in another nine taxa.

Of the 51 taxa with overall population declines exceeding 25% at 10 years/three generations, only 18 were part of the 45 taxa with the greatest overall population losses at one week or one year post fire. This is because by 10 years/three generations, the impacts of the 2019–20 fires persisted, potentially due to barriers to natural recolonisation and/or compounding effects of other threats on many taxa. The 51 taxa comprised 14 fish, 12 mammal, eight frog, seven bird, six spiny crayfish and four reptile species. The top six species with the worst population predictions at 10 years/ three generations were all fish.

Experts estimated that mortality continues to be elevated in the year after fire, and most populations of the assessed taxa continue to decline. Between one year and 10 years/three generations, population recovery varied across the taxonomic groups, from only 6% in fish taxa to 92% in spiny crayfish taxa. Under an assumption of continuation of existing management, population recovery back to pre-fire levels was plausible for only 79 of the 173 taxa (46%) involved in the elicitation, and likely for only 19 of the 173 taxa (11%). Reptiles were the group with the largest proportion of taxa that could plausibly recover (87%), followed by birds (71%), frogs (45%) and mammals (37%), whereas fish and spiny crayfish had the lowest proportion of taxa that were predicted to plausibly recover (19% and 4% respectively).

Uncertainty: Experts were more confident about their estimates for population change closer to the fire event, than one year after fire, and then 10 years/three generations after fire. Experts were less confident about the impacts of severe fire than mild fire. Uncertainty about the immediate impacts of severe fire was least for birds and greatest for reptiles, then frogs and fish. Field data to confirm the impacts of fire across all taxonomic groups would help reduce expert uncertainty, and especially so for reptiles, frogs and fish.

Conclusions

Conservation status review: Based on the estimates for predicted population declines, and information about the pre-fire population status and trends summarised in the EPBC Act lists, the IUCN Red List, relevant Action Plans and other expert assessments, we suggest that at least 66 currently unlisted taxa, and possibly as many as 91 currently unlisted taxa, are eligible for listing under the EPBC Act as a result of the 2019–20 fires, in some cases compounding declines that had not yet been recognised under national legislation (Table a). Twenty-three taxa, possibly as many as 34 taxa, that are currently listed under the EPBC Act may now be eligible for uplisting (Table a). In addition, the status of another 37 listed taxa has worsened as a result of the 2019–20 fires, but this deterioration either did not meet thresholds required for uplisting, or these taxa were already at the highest possible conservation status (Critically Endangered; n = 8).

Our assessment indicates that recovery will be slow for most fire-affected species, and that for some taxa the fires have accelerated pre-existing declines. Our predictions for population recovery are optimistic, because we assumed no extreme droughts or fire events over the next 10 years/three generations. However, such events are predicted to increase in frequency, and extensive, severe fires that re-occur before full recovery has been achieved since the previous fire(s) will cause a progressive downward population trajectory, beyond those predicted by our assessment. Evaluating whether additional management interventions could mitigate fire impacts (i.e. improve resistance) and facilitate the recovery (i.e. enhance resilience), especially for taxa with relatively longer recovery times, is an important next step.

Our assessment provides evidence that can be used in conservation status reviews. Due to data limitations, we relied on expert elicitation combined with spatial analyses of fire extent overlaps with species distributions of variable quality. However, on-ground surveys and long-term studies to describe the distribution, status and trends of populations, their exposure to threats, and their response to management, are required to confirm these expert assessments, and to provide a stronger platform for future conservation assessments and recovery planning.

Table a. *Summary of conservation status review, showing the number of taxa assessed and the number of those that are listed (or unlisted) under the EPBC Act, and the numbers of taxa recommended for listing assessment or re-assessment.*

Taxonomic group	No. taxa assessed	No. of these taxa already listed		No. of these taxa not already listed		No. listed taxa suggested for uplisting (and those to consider)		No. unlisted taxa suggested for listing assessment (and those to consider)	
Birds	68	11	16%	57	84%	1	9%	20 (+4)	35-42%
Mammals	56	21	38%	35	62%	9 (+4)	43-62%	1 (+4)	3-11%
Reptiles	45	9	20%	36	80%	1 (+4)	11-44%	5 (+4)	14-25%
Frogs	66	21	32%	45	68%	11 (+1)	52-57%	7 (+7)	16-31%
Fish	21	9	43%	12	57%	1 (+2)	11-22%	10 (+2)	83-100%
Spiny Crayfish	32	0	0%	32	100%	-		23 (+4)	72-84%
Total	**288**	**71**	**25%**	**217**	**75%**	**23 (+11)**	**32-48%**	**66 (+25)**	**30-42%**

Introduction

The incidence of major fires is increasing globally, driven mainly by anthropogenic climate change (Jolly *et al.* 2015; Bowman *et al.* 2020b). In Australia, a three-year drought and record low rainfall and high temperatures in late 2019, created extreme fire weather conditions (King *et al.* 2020; Nolan *et al.* 2020; van Oldenborgh *et al.* 2020; Abram *et al.* 2021). Between September 2019 and March 2020, over 10 million hectares of habitat for native plants and animals burned in a fire season that was longer, involving severe fires of greater extent than ever recorded in Australia's temperate and subtropical forests (Collins *et al.* 2021; Lindenmayer and Taylor 2020; Wintle *et al.* 2020). Over 20% of Australia's eucalypt forests burned, much higher than the annual average (2%) for this biome (Boer *et al.* 2020; Bowman *et al.* 2020a). Ecosystems that rarely experience fire also burned, including subtropical rainforests (DPIE 2020; Kooyman *et al.* 2020). Aquatic habitats within and downstream of burnt areas were also heavily impacted (Silva *et al.* 2020).

Much of Australia's biota has co-evolved with fire (Gill *et al.* 1999; Bowman *et al.* 2012), but extensive and high severity fires could exceed the tolerances of many species, and cause substantial population declines. Fires, especially severe fires, can kill animals directly. Animals that survive the fire itself may die in the following months from lack of resources (food, water, shelter), heavy sedimentation and water quality deterioration in aquatic environments, and increased exposure to predation, competition, and disease. Analyses of species distributions in relation to the spatial extent of the 2019–20 bushfires in eastern and southern Australia estimated that many hundreds of invertebrate species (Woinarski *et al.* 2020) and many dozens of vertebrate species were impacted (Legge *et al.* 2020; Ward *et al.* 2020), and that three billion reptiles, mammals, birds and frogs were killed, displaced, or otherwise affected (van Eeden *et al.* 2020).

The capacity for populations to recover may be reduced after such extensive fires. When unburnt refuges are scarce, and populations are much diminished, population recovery both via in-situ reproduction and dispersal from nearby unburnt areas is constrained (Banks *et al.* 2017; Nimmo *et al.* 2019; Shaw *et al.* 2021). Some key resources, such as large tree hollows or arboreal foods, may be rare for decades after fire, further limiting population recovery (Lindenmayer *et al.* 2013; Lindenmayer *et al.* 2020a). Some threats, such as timber-harvesting, may worsen the immediate severity and impacts of fire (Lindenmayer *et al.* 2020b; Bowman *et al.* 2021), and the impacts of other threats may be amplified in the post-fire environment (Doherty *et al.* 2015; McGregor *et al.* 2016; Geary *et al.* 2020). In addition, many fire-affected species were already declining, fragmented, or had reduced populations before the fires as a result of drought, and ongoing threats such as predation and competition from introduced species, disease and land-clearing (Geyle *et al.* 2018; Geyle *et al.* 2020; Gillespie *et al.* 2020; Lintermans *et al.* 2020).

A review of the conservation status of fire-impacted species is important to ensure that these species benefit from legislative protection and conservation planning to support their recovery. Some fire-impacted species were already considered threatened before the 2019–20 fires, and their conservation status may have worsened, particularly if their capacity to recover from population losses experienced during and after the fire is constrained. Other species that were previously considered secure may have experienced substantial declines and similarly face constrained recovery, to the extent that they may now qualify for listing as threatened.

In this report, we present information to aid a review of the conservation status of fire-affected vertebrate taxa, and taxa in one group of invertebrates (spiny crayfish), whose distributions overlapped with the 2019–20 fires of eastern, southern and south-western Australia. The assessment contains two components: first, an analysis to estimate the proportions of the distribution of each species that overlapped with fires of varying severity. Second, for a subset of these species, we also carried out a structured expert elicitation to estimate the proportional population change after fires of different severity, and the ensuing rate of population recovery. The expert judgements were then combined with the spatial analyses to generate estimates of overall population change from before the 2019–20 fires, to immediately after (up to one week post-fire), one year after, and then out to 10 years/three generations (whichever is longer) after the fires. Using structured expert elicitation (informed by any available relevant data) is the only option for estimating fire impacts across a large set of species, given there is so little documented evidence of species population losses as a result of fire, and particularly since the 2019–20 fires were unprecedented in scale.

Background and aims

This assessment follows on from a preliminary analysis carried out in January-February 2020 by the Wildlife and Threatened Species Bushfire Recovery Expert Panel. This Panel was convened by the Australian Government to help guide the national response to the bushfire crisis. One of the Panel's immediate priorities was to identify which fire-affected species were most urgently in need of management intervention in the weeks and months following the fires. The Panel rapidly developed an assessment framework based on the pre-fire imperilment of each species, the proportion of their range that overlapped with the fire extent, and whether they had ecological, behavioural and life-history traits that could make them more vulnerable to the direct and indirect impacts of fire (Legge *et al.* 2020).

Using this framework, the Panel assessed all reptile, frog, bird and mammal taxa whose distributions overlapped with the fire extent; and all fire-affected fish taxa that are listed, or proposed for listing, by either the International Union for Conservation of Nature (IUCN) or by the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The Expert Panel also assessed fire susceptibility in a small number of invertebrate species: all fire-affected terrestrial invertebrates listed by the EPBC Act, and all spiny crayfish in the genus *Euastacus*, a genus whose taxonomy, status and distribution is currently being reviewed by taxon experts; other invertebrate species were considered in a complementary project. This assessment prioritised 119 of the most fire-affected species (23 reptile species, 16 frog species, 17 bird species, 20 mammal species, 5 invertebrates, 22 spiny crayfish and 16 fish) for management intervention (Legge *et al.* 2020).

Now, in 2021, an assessment of fire impacts across species is worth revisiting because since the Panel's analysis in early 2020, new data sources have become available:

- A national fire severity map that describes variation in fire severity across the fire-affected area. This allows differentiation between areas where habitat was burnt lightly versus areas where the canopy was completely consumed. Understanding the spatial arrangement of fires of varying severity in relation to species' distributions is important, because species respond differently to low and high severity fires.
- A review of unpublished data on population genetic structure across many of the fire-affected frogs, reptiles, birds and mammals (Catullo and Moritz 2020). This report resolves some taxonomic ambiguities, ensuring that previously cryptic taxa are properly considered in the assessment. The report also improves the geographic delineation of distributional boundaries between candidate species and subspecies, again leading to improved estimates for the spatial impacts of the fires on fire-affected taxa.
- For some species, early data became available in 2020-2021 at some sites, on the population response to fire.

In addition, in a less time-pressured situation, two additional steps can be included:

- Species distribution models and range maps for priority species can be updated.
- Expert input can be gathered in a structured way. In particular, expert judgement about species response to fires of varying severity can be gathered and combined with information on the proportion of each taxon's range that was affected by such fires to generate enhanced estimates of fire impact. Expert elicitation is necessary for this step because there are so few data available on species' responses to fire, especially to fires of the scale of the 2019–20 bushfires.

Given these new data and information resources, our **aim** was to improve estimates of the impacts of the 2019–20 bushfires on native vertebrate species and spiny crayfish species, and describe the likely trajectories for population recovery across species. This work is designed to support reviews of the conservation status for fire-affected taxa, and to inform prioritisation of fire-affected taxa for management investment.

The work presented in this report is one part of a larger project that included two other, interlinked aims:

- Improve our understanding of the species' traits that affect susceptibility to fire events and their capacity to recover, to inform response to future such events.
- Understand the extent to which current management is supporting the recovery of species, and where extra investment is needed to increase the likelihood and pace of that recovery.

These two aims are addressed in separate reports.

Methods

Assessment area

The assessment considered taxa with distributions within, or overlapping, the 2019–20 fire extent (as described by the National Indicative Aggregated Fire Extent dataset (NIAFED)) that lies within the Preliminary Analysis Area delineated by the Department of Agriculture, Water and the Environment (DAWE). The Preliminary Analysis Area covers the bioregions of southern and eastern Australia that were most heavily affected by the 2019–20 bushfires, including areas within Western Australia, South Australia, Victoria, Tasmania, New South Wales, the Australian Capital Territory and Queensland. The fire extent within the Preliminary Analysis Area covers 104,000 km^2.

Fire spatial data

In early 2020, the Expert Panel used the NIAFED to estimate the proportion of each taxon's range that was potentially fire-affected. Here, we instead used the national fire severity dataset developed by DAWE in collaboration with the NSW Department of Planning, Industry and Environment. The Australian Google Earth Engine Burnt Area Map (AUS GEEBAM) describes variation in fire severity across the fire-affected area, and maps pockets of unburnt vegetation within the fire extent boundaries. Thus, it is a more accurate estimate of the area burnt within the fire extent footprint, and also allows estimation of the proportion of a taxon's distribution that burned in fires of varying severity. The spatial extent of AUS GEEBAM is the fire footprint defined by NIAFED to 25 February 2020. Although additional areas burnt after 25 February, mostly in southeast Qld, they were much smaller in extent (8279 ha, or 0.079% of the total area covered by NIAFED).

The AUS GEEBAM used Sentinel-2 satellite imagery from before and after the 2019–20 bushfires to calculate the difference in the normalised burnt ratio (dNBR), and categorise burnt areas into fire severity classes (Table 1). Visual interpretation was used to calibrate the processed images and severity classification; this allowed for adjustments to the classification to account for differences among bioregions and vegetation types (as defined by the National Vegetation Information System). To help with this, the dNBR was also calculated for reference unburnt areas within 2 km of the NIAFED edge, for every bioregion and vegetation type. The Low and Moderate fire classes were combined in the AUS GEEBAM map, because the delineation between these two categories was known to be poor. The overall accuracy of the AUS GEEBAM dataset is difficult to assess, as it has not been comprehensively validated by ground-truthing. However, it is the only nationally consistent product that attempts to present spatial variation in fire severity across the Preliminary Analysis Area. See (DAWE 2020) for more details.

Table 1. *The fire severity classes in the AUS GEEBAM.*

GEEBAM Value	GEEBAM Class	Description
1	No data	Areas outside NIAFED or NVIS categories that do not represent native vegetation (e.g. cleared land, water)
2	Unburnt	Little or no change observed between pre-fire and post-fire imagery
3	Low and Moderate	Some change or moderate change detected when compared to reference unburnt areas outside the NIAFED extent
4	High	Vegetation is mostly scorched
5	Very High	Vegetation is clearly consumed

Species included in the assessment

The taxa included in the assessment were based initially on the starting set of taxa that were part of the Jan-Feb 2020 assessment carried out by the Expert Panel – vertebrates, EPBC-listed invertebrates and spiny crayfish whose distributions intersect with the 2019–20 NIAFED restricted to the Preliminary Analysis Area. From the starting list, we then:

- Omitted the five fire-affected invertebrate species listed under the EPBC Act, as population declines across invertebrates are being assessed more comprehensively in a parallel project.
- Removed taxa with very low estimates of overlap between the NIAFED fire extent and their distributions because these taxa are unlikely to have experienced an immediate and sustained population decline as a result of the fires that would cause a change in conservation status. The thresholds for very low fire overlaps were:
    - Taxa with < 10% of their distribution overlapping the fire extent, if they were listed under the EPBC Act, in the IUCN Red List, or by a relevant Action Plan or similar expert assessment; and
    - Taxa with < 25% of their distribution overlapping the fire extent, if unlisted.

  - Eight species with low fire overlaps were retained, if expert opinion indicated the fire overlap could be an underestimate, or we considered that improved distribution data could appreciably change the fire overlap (Northern Eastern Bristlebird *Dasyornis brachypterus monoides*, Southern Water-skink *Eulamprus tympanum*, Long Sunskink *Lampropholis elongata*, Guthega Skink *Liopholis guthega*, Border Thick-tailed Gecko *Uvidicolus sphyrurus*, Mud-Gully Crayfish *Euastacus dalagarbe*, Blue-Black Crayfish *Euastacus jagabar*, New Hairy Crayfish *Euastacus neohirsutus*).

- Included subspecies (recognised in the Australian Faunal Directory), when fire-affected species comprised subspecies that may have been separately and differentially impacted by fire.
- Included subspecies when the distribution of the parent species minimally overlapped with fire (and thus this taxon did not meet the threshold or inclusion), but the distribution of a subspecies did have a fire overlap that exceeded the threshold for inclusion.
- For bird species that migrate, we included both their overall range, as well as their breeding range.
- Modified the list of taxa in-scope based on the recent report of Catullo *et al.* (2020), which summarises the available unpublished evidence of taxonomic updates to many fire-affected mammal, frog, reptile and bird taxa, and refines information on the geographic location of the boundaries between these taxa. This information has not yet flowed through to taxonomic recognition in the Australian Faunal Directory, but by including it, we ensured the assessment was based on the most current taxonomic information.

The final list of taxa in the assessment covered 288 taxa, four of which had two different distributions across seasons (the migratory birds) resulting in 292 intersects of fire mapping with 288 taxon distributions (Table 2). We have high confidence that this list encompasses all the Australian vertebrate taxa and spiny crayfish (*Euastacus* spp.) that have been most affected by the 2019–20 fires.

Hereafter, we use 'species' unless we are referring to subspecies or both species and subspecies, in which case we use 'taxa'.

Table 2. The set of taxa for assessment (full list in Appendix 1), and their current conservation status. Candidate species and subspecies identified in Catullo et al. (2020) are counted. Action plans or equivalent assessments are Chapple et al. (2019), Garnett et al. (2011), Gillespie et al. (2020), Lintermans (2020), Lintermans (2019), Woinarski et al. (2014).

Group	Number of taxa (species)	Taxa listed by EPBCA (assesses subspecies or species)	Species listed by IUCN (only assesses species)	Taxa listed by Action Plan or another expert assessment	Taxa not listed by EPBCA, IUCN, Action Plan or other expert assessment
Birds	68 (54 species) including 4 migratory bird species with two alternative ranges (making 72 intersects)	11 plus 5 listed migratory species	5 species	15	46
Mammals	56 (46 species); 1 taxon is the listed population of the koala	21 (17 species)	17 species	21 taxa (19 species)	24
Frogs	66 (47 species)	21 (14 species)	24 species	19	34
Reptiles	45 taxa (40 species)	9 (9 species)	16 species	14	22
Fish	21 (including 5 undescribed species)	9 (8 species)	19 species	19	2 (not yet described)
Spiny crayfish	32 (32 species, including 3 undescribed)	0	25 species	n/a	7
Total	**288 taxa (240 species)**	**60**	**106**	**88**	**135**

Species distribution data

There is no single source of curated distribution data for Australia's native fauna. We collated species distribution information, and species records, from multiple sources.

For almost half the taxa (132 out of 288, all terrestrial species), we developed new species distribution models (SDMs) for this assessment. We also sourced pre-existing SDMs and range maps for most taxa in the assessment. Where two alternative maps were available for the same taxon, we consulted with experts to select the map option that best reflected that taxon's distribution. Below, we provide further details on the distribution data sources, summarise which sources were available across the animal groups, and describe the process for bringing expert input into map selection and preparation.

Species Distribution Models:

We produced SDMs to predict contemporary distributions for 132 mammal, bird, frog and reptile taxa based on records collated from six databases: 1) New South Wales BioNet Atlas; 2) Victorian Biodiversity Atlas; 3) Queensland WildNet database; 4) Biodiversity Databases of South Australia; 5) BirdLife Australia; 5) Atlas of Living Australia (ALA) and 6) Global Biodiversity Information Facility (GBIF). Several species names were not referenced by taxonomic checklists (e.g. GBIF Taxonomic Backbone), so synonyms were also searched for and manually merged. We screened occurrence records for coordinate errors, including missing or invalid coordinates; equal longitude and latitude; coordinates falling into the ocean; state and national centroids; capital cities, or specimen collection institutions. We removed records dated before 1990 and those with coordinate uncertainty that was either >1000 m or unknown. For two species of mammals that have experienced recent range contractions (Smoky Mouse *Pseudomys fumeus*, Broad-toothed Rat *Mastacomys fuscus mordicus*), we re-ran the SDMs after restricting the observation set to post-2000. Using the raster package in R we overlaid the remaining records on a 250 x 250 m raster grid of Australia and filtered records to ensure there was only one record per species in a cell. This step was necessary to remove duplicates of the same record held across two or more databases. Records were visually inspected for outliers and discarded if deemed to be outside the species' range. Species with records in <20 grid cells were excluded from modelling.

We collated a set of 52 topographic, climatic and environmental variables thought to influence the distribution of priority species. Spatial variables were projected to a common equal area coordinate system prior to analysis (Australian Albers; EPGS: 3577). We refined our list of spatial variables by removing highly correlated variables with a correlation coefficient >0.7 and a variance inflation factor (VIF) >10. This resulted in a reduced set of 16 spatial covariates. We modelled habitat suitability with presence-only data using *MaxEnt* models in the R package maxnet (Phillips *et al.* 2017). We used cross-validation to tune the regularisation parameter. To reduce bias associated with occurrence records, we used target-group-background samples when there were more than 1000 records from the same taxon per state with occurrence records. Otherwise, we generated 10,000 random samples from the background landscape (i.e. states in which the species is found, or in the case of island endemics, the island on which it is found). The random background samples were taken with a higher intensity towards roads and cities to take account for accessibility bias, using a 1 km^2 resolution travel-distance-to-cities layer (Weiss *et al.* 2018). We evaluated the predictive performance of the models using two threshold-independent metrics calculated in a 5-fold cross-validation setting: the area under the ROC curve (AUC) and the continuous Boyce index.

We predicted the distribution for species then converted the continuous prediction of the SDMs to binary range maps, using an optimum threshold based on testing presence-background data. The threshold was selected by maximising the "sum of sensitivity and specificity" recommended by Lui *et al.* (2013) as the proper threshold selection method for presence-only data. Thresholds were calculated for each testing fold and then averaged over all cross-validation folds.

Range maps for mammal taxa:

Range maps were available for 29 mammal species listed under the EPBC Act. These were developed by the Environmental Resources Information Network (ERIN) team within DAWE (https://www.environment.gov.au/about-us/environmental-information-data/erin), who first developed SDMs then converted these to range maps by displaying areas where the species was 'known' and 'likely to occur'. The range map from this source for Silver-headed Antechinus, *Antechinus argentus*, was very poor because of few records. We contacted experts (S. Batiste, A. Baker) currently working on this taxon, and created a range map based on records supplied. We sourced a range map for the recently described Sugar Glider *Petaurus breviceps*, and a range map for the Kangaroo Island Dunnart *Sminthopsis fuliginosus aitkeni*, from experts who have recently modelled their distributions (H. Moore; R. Hohnen). We also sourced a range map for the Grey-headed Flying-fox *Pteropus poliocephalus*, from a recent publication (Currey *et al.* 2018).

Range maps for reptiles:

Species distribution polygons for 44 reptile taxa were compiled during the 2017 reptile assessment carried out by IUCN (Tingley *et al.* 2019) and expert updates to this spatial dataset have been continuously curated (R. Tingley, unpublished data). The range maps encompass occurrence records for each species, but ignore habitat availability within the polygon, and therefore may overestimate the occupied range.

Range maps for frogs:

Species distribution polygons for 66 frog taxa were compiled during IUCN Red List assessments, and expert updates to this spatial dataset have been continuously curated (S. Macdonald, unpublished data). The range maps encompass occurrence records for each species, but ignore habitat availability within the polygon, and therefore may overestimate the occupied range.

Range maps for birds:

Range maps based on minimum convex polygons for 68 taxa (including 4 with seasonal ranges), based on observation records held by BirdLife Australia, were clipped to a vegetation map based on the National Vegetation Information System (NVIS) that excluded freshwater, salt lakes, lagoons (24); cleared, non-native vegetation, building (25); naturally bare sand, rock, claypan, mudflat (27); and sea and estuaries (28). We explored the option of using alpha hulls around the same observation points, but minimum convex polygons were deemed more appropriate by taxon experts.

Range maps for fish:

Sub-catchment distributions were available for all 19 fish taxa from data compiled during the 2019 IUCN Red List assessment for Australian freshwater fish (https://www.iucnredlist.org/). The IUCN range maps for two species were inaccurate, and we created new maps based on observation records made available to us by species experts (Non-parasitic Lamprey *Mordacia praecox* (T. Page), SE Victorian Blackfish *Gadopsis* sp. nov. SE Victoria (T. Raadik)). All fish ranges were clipped to a watercourse layer at 250 m^2 resolution.

Range maps for spiny crayfish:

Species distribution polygons for all 32 spiny crayfish taxa were available from McCormack (2012). We clipped these polygons to waterways, with a buffer width that varied according to the species burrow type: 250m for species with burrows that are permanently connected to the stream; 500 m for species whose burrows are connected to the water table; and no buffer for species with burrows that are independent of the water table.

Feedback on mapping information by experts:

All maps were reviewed by taxon experts (the taxon lead and several to all experts in their group). Feedback on mapping inaccuracies were used to source additional observation records or restrict the observation set used in SDM creation, and adjust the parameters of the modelling. If we were aware of detailed mapping products for any taxa that already existed, we contacted those colleagues to ask if they could share that information (either the observation records, or their mapping product; 2 fish taxa, 4 mammal taxa; described above). In the final map preparation step, to reduce the potential for overprediction, we clipped SDMs by the known range maps for frogs and reptiles (see below), and to native vegetation for mammals and birds (i.e. using NVIS, and excluding freshwater, salt lakes, lagoons (24); cleared, non-native vegetation, building (25); naturally bare sand, rock, claypan, mudflat (27); and sea and estuaries (28), which covered only a small fraction of the study region). Finally, where more than one mapping product for a taxon was available, experts then selected the preferred map (i.e. the map that they considered best represented the taxon's distribution) for the fire overlap analysis.

Note that all maps that we used were presence-absence, which does not allow for consideration of variable density across a species' range. Including density information would improve resolution in estimates of proportional population loss, but is not available for most species at national scales.

A summary of which mapping data sources were available across the animal groups is shown in Table 3.

Table 3. Source data for distributions of taxa included in the assessment, for each animal group. The total number of taxa included in the spatial analysis for each group is shown in brackets.

Taxon distribution data source	Mammal (56)	Reptile (47)	Frog (66)	Bird (68)	Fish (21)	Crayfish (32)
SDMs developed during this assessment	48	21	48	14		
Range maps developed from records supplied by experts	4				2	
Range maps developed from habitat modelling (DAWE)	29					
Range maps for reptiles (R. Tingley)		45				
Range maps for frogs (S. MacDonald)			66			
Range maps for birds (G. Ehmke)				72*		
Range maps for fish (IUCN)					21	
Range maps for spiny crayfish (McCormack)						32

* includes 4 migrants with seasonal ranges

Spatial analysis of overlaps between species distribution and fire severity classes

The AUS GEEBAM raster was reprojected to equal area projection Australian Albers (GDA94), resampled to 250 m resolution to match the SDMs, and clipped to the Preliminary Analysis Area. We then calculated the proportion of each species range affected by fire of each severity class from the AUS GEEBAM using a Python script in QGIS.

To facilitate subsequent steps in the assessment, we simplified the 5 fire classes in Table 1 down to 3 (Table 4; Fig. 1), as follows:

- Fire class 1 refers to areas within the mapped extent that either represented cleared area or water, or that could not be assigned to a fire severity class. Fire class 1 covered very small areas of species distributions, typically less than 1%. Nevertheless, we excluded the proportion mapped as class 1 from the calculations, by recalculating the proportions in the other fire classes, when class 1 was removed from the taxon distribution:

  E.g. Recalculation for % distribution in fire class 2 would be: fire class 2/(100-fire class 1).

- We calculated the proportional area affected by 'severe' fire by summing the proportions of each taxon's distributions in GEEBAM fire classes 4 (high severity) and 5 (very high severity).
- We calculated the proportional area affected by 'mild' fire in two ways:
  - by summing the values in GEEBAM fire classes 2 (no or little change) and 3 (low-moderate severity);
  - by including only the value in GEEBAM fire class 3 (low-moderate severity).

The estimates for overall population decline presented in the body of the report are based on using the first alternative for the proportion of a species' distribution burnt in a mild fire, because an unknown fraction of these areas was burnt (the mapping cannot distinguish between very low severity fire and no fire); because some unburnt patches within the fire footprint could be so small, they may not provide useful habitat; and because the second alternative will underestimate the area burnt in mild fire. Recognising that our approach may slightly overestimate the area burnt in mild fires, we examined the difference between the two alternative estimates of proportional population decline for each species. For most species, the difference in the overall decline produced using these two alternative classifications was less than 2%. In the few species where the divergence was large (> 5%), we present both estimates of population decline for that species, in the Results. We also present the estimates for overall population decline, using AUS GEEBAM class 3 values only, for all species, in Appendix 1.

- We calculated the proportion of a species' distribution that was unburnt by subtracting the proportional areas burnt (within the preliminary analysis area) in mild and severe fires from 100.

Table 4. The fire severity classes in the AUS GEEBAM, mapped onto the simplified fire classification used in this assessment. AUS GEEBAM fire class 2 includes areas that are unburnt or lightly burnt, therefore we calculated the overlaps between species distributions and the fire severity map when fire class 2 was categorised as unburnt, and also when it was categorised as burnt (in low severity fire).

GEEBAM Value	GEEBAM fire class description	Fire classification used in this assessment	
		Alternative 1	Alternative 2
1	No data: Areas outside NIAFED or NVIS categories that do not represent native vegetation (e.g. cleared land, water)	Excluded	
2	Unburnt: Little or no change observed between pre-fire and post-fire imagery	Mild fires	Unburnt
3	Low and Moderate: Some change or moderate change detected when compared to reference unburnt areas outside the NIAFED extent		Mild fires
4	High: Vegetation is mostly scorched	Severe fires	
5	Very High: Vegetation is clearly consumed		

Fig. 1. Examples of habitat that has burnt in low to moderate severity (some or all ground vegetation affected by fire: upper canopy not affected or partially scorched); high severity (all ground material affected by fires, upper canopy heavily scorched); and very high severity fire (all ground material affected by fires, upper canopy heavily scorched to completely consumed). In subsequent analyses, low-moderate severity fires are called 'mild' fires, and high to very high severity fires are called 'severe' fires. (Photo credits: Phil Zylstra).

Fire impacts on aquatic species

An aquatic impacts extent model

Fires can cause a range of impacts for aquatic species, by increasing water temperatures, stream pH, nutrients, ash, and sedimentation (Neary *et al.* 2005; Rieman *et al.* 2012; Silva *et al.* 2020). Fires, especially severe fires, can damage soil structure, causing hydrophobicity that increases erosion and the risk of heavy sedimentation in waterways. Heavy sediment can clog the gills of fish, and smother spawning and feeding substrates. The influx of carbon into waterways can de-oxygenate water and cause mass kills. The influx of nutrients can cause rapid growth of cyanobacteria, also reducing oxygen levels and killing aquatic fauna. Key factors in whether heavy sedimentation occurs include steep topography, soil features, severity of the fire (greater vegetation loss means less vegetation to intercept rainfall or overland flow), and the timing, scale, intensity and duration of rain after fire (Neary *et al.* 2005). These impacts can occur tens of kilometres downstream from the fire itself (Lyon and O'Connor 2008; Silva *et al.* 2020), so intersecting the fire severity map alone with the distributions of aquatic species would substantially underestimate how impacted those species were by fire.

We developed a sedimentation risk index for fire-affected rivers and streams within the Preliminary Analysis Area by modifying an existing soil erosion risk model, the Revised Universal Soil Loss Equation (RUSLE), to account also for spatial variation in fire severity and high daily and fortnightly rainfall events. The RUSLE calculates the annual soil loss (A) by water using a linear equation that is the product of six environmental factors:

$$A = R \times K \times L \times S \times C \times P$$

where A is the average annual soil erosion at each cell; R is the rainfall-runoff erosivity factor; K is the soil erodibility factor; L is the slope length factor; S is the slope steepness parameter; C is the cover management factor; and P is the support practice factor (Teng *et al.* 2016).

Using ArcGIS (version 10.4), we created a spatial layer of rainfall events between 15 January 2020 and 15 March 2020 that were likely to cause surface flow using daily and fortnightly rainfall data from the Australian Water Availability Project via http://www.bom.gov.au/jsp/awap/. The mean and standard deviation for daily and fortnightly rainfall for the period between the 15th January to the 15th of March, was calculated for each raster cell, for 2000 to 2019. Rainfall at each raster cell between 15th January and 15th March 2020 that was more than 1 standard deviation above the 20-year average rainfall (daily or fortnightly) was classed as a high rainfall event, and the raster cell was given a value of 2, whereas all other values were assigned a value of 0.

We classified every raster cell in the AUS GEEBAM to a score of 3 if burnt at high or very high fire severity, a score of 2 if burnt at low-moderate severity, and a score of 0 if cells were unburnt or had no data.

We expanded the RUSLE formula (black text) by incorporating fire severity and rainfall (red text), as follows:

$$A_{fire} = R \times K \times L \times S \times C \times P \times F \times D$$

where F is the fire severity score and D is the rainfall score.

Using the Bureau of Meteorology's Australian Hydrological Geofabric raster, which is a detailed, fully connected and directed stream network, A_{fire} values were assigned to the downstream network nodes within the catchment. These values were consecutively summed to the next downstream node, up until 50 km distance had been achieved from the top of the catchment (with that distance based on observations in Lyon and O'Connor 2008; Silva *et al.* 2020).

The $RUSLE_{fire}$ model was validated by cross-checking the model predictions against on-ground observations of heavy sedimentation events. Seventeen observations were made by co-authors of this report (T. Raadik and M. Lintermans); the model predicted sedimentation events correctly at 82% of these sites (Fig. 2a,b). Another information source reported sedimentation events, of varying but undescribed severity, at 15 sites (Silva *et al.* 2020); our model predicted 6 of these sites (Fig. 2c), with the mismatches occurring because Silva *et al.* (2020) reported fish deaths slightly further downstream than we set the model to project to (i.e. > 50 km). This suggests our model was conservative.

The A_{fire} scores for every stream node were displayed in a raster file. Each cell in the stream between nodes was assigned a value that was the average of the nearest upstream and nearest downstream node.

The A_{fire} scores were divided into three classes of sedimentation risk (Fig. 3):

- No risk (outside or too far downstream from the fire extent)
- Mild risk (< mean value of 11.5)
- Severe risk (> mean value of 11.5)

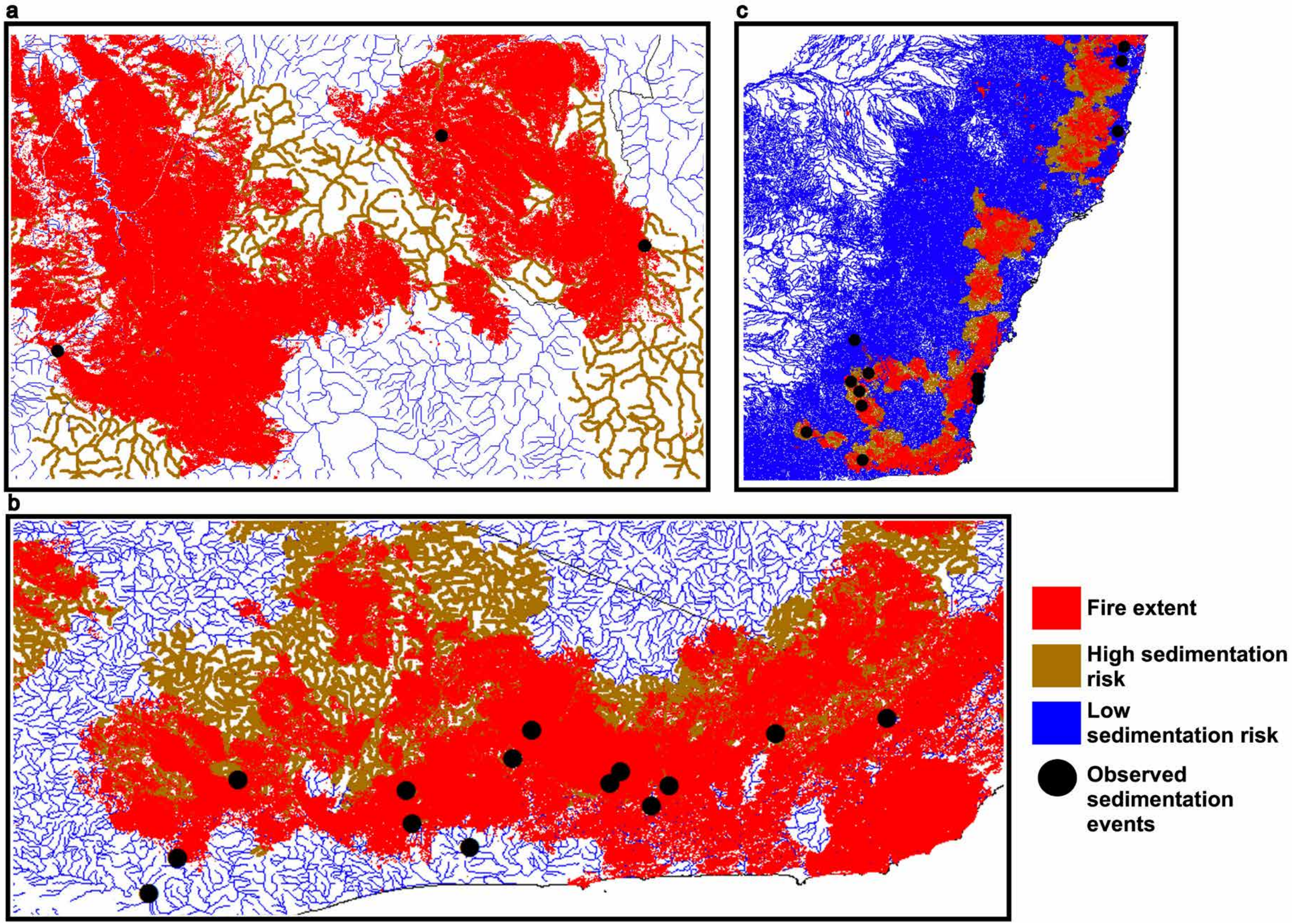


Fig. 2. *Three different datasets were used to validate the model. a) M. Lintermans, pers. observations, b) T. Raadik, pers. observations; c) Silva et al. 2020. Brown lines indicate waterways with severe sedimentation risk, blue lines indicate mild risk, and black circles are the observed sedimentation events.*

Fig. 3. *Examples of waterways facing mild and severe sedimentation. Mild risk applies to waterways with some (or all) of these features: there is little or some instream sediment or ash, burnt debris may or may not be in the stream, and there are little or no obvious impacts on water quality or clarity. High risk applies to waterways with some (or all) of these features: substantial ash and sediment in the stream, substantial burnt debris in the stream, evidence of bank or tributary erosion, and heavy impacts on water quality or clarity. (Photo credits. Left: N. Whiterod; Right: R. McCormack)*

Estimating the overlap between the aquatic impact extent model and species distributions

We rasterised the aquatic impacts map developed above to 250 m^2 resolution to align with the fire severity map.

Fish: We clipped fish ranges to the aquatic impacts map and calculated the proportion of each sedimentation class (i.e. no aquatic impact risk, mild aquatic impact risk and high aquatic impact risk) in each species range.

Platypus and turtles: We carried out the same step for one mammal species (Platypus, *Ornithorhynchus anatinus*) and three turtle species (*Wollumbinia belli, Wollumbinia georgesi, Wollumbinia purvisi*) that could be more affected by aquatic impacts, than by above ground fire impacts, and compared the estimates for population decline derived using both the aquatics impact model and the fire severity map.

Spiny crayfish have three burrow types that affect their fine-scale distribution, and result in different exposure to above ground fire impacts and aquatic impacts. Species with burrows permanently connected to the waterway (type 1; 11 species), are constrained to occur very close to the streams, and are vulnerable to fire-caused aquatic impacts. Spiny crayfish with burrows connected to the watertable (type 2; 19 species) are generally found close to waterways (we assumed within 500 m of stream networks). The third type of burrow in spiny crayfish collects rainwater and is not connected to water at all (two species) and these species can occupy terrestrial habitats near and away from streams.

Spiny crayfish species with burrow types 2 or 3 may be affected by above ground fire; we calculated the proportion of each fire severity classes in each species' range. In contrast, spiny crayfish with burrow type 1 could be impacted by both above ground and aquatic impacts. For these, we first combined the aquatic impacts risk model and the fire severity map to create a 'combined fire severity-sedimentation' risk map. Cells were given a *high* combined risk if the aquatic impacts risk was high regardless of the above ground fire severity; a *moderate* combined risk if aquatic impacts risk was high in unburnt habitat; a *moderate* combined risk for mild aquatic impacts risk in areas of high or very high fire severity; *low* combined risk in mild aquatic impacts risk and low-medium fire severity, and; *no* combined risk in mild aquatic impacts risk and unburnt habitat (Table 5). For spiny crayfish species with burrows connected to the waterway, we calculated the proportion of the 'combined fire severity-sedimentation' classes within each species range.

Table 5. *Impact matrix for spiny crayfish species with burrows that are permanently connected to streams. In-stream impacts convey greater risk than terrestrial fire, because the crayfish are partially protected from fire in their burrows. The combination of unburnt riparian vegetation and severe sedimentation risk integrates to a 'mild' impact, because spiny crayfish can exit their burrows to escape a sediment pulse for a short time.*

	Fire severity in riparian areas		
	Unburnt	Low to Moderate severity	High to Very High severity
Low risk of aquatic impact	No impact	Low impact	Moderate impact
High risk of aquatic impact	Moderate impact	High impact	High impact

Expert elicitation: estimates of local population response to fire

From the 288 taxa included in the spatial analyses, we selected a subset of 143 species to be the focus of an expert elicitation to estimate proportional population change as a result of fire. Paring down the species set was necessary to keep the elicitation burden on experts manageable. We chose species with the highest initial estimates for distributional overlap with fire and species about which experts were most concerned. The 143 species included 173 taxa; we assumed subspecies responded to fire in the same way as the species.

We used the structured four-step approach of the IDEA (Investigate, Discuss, Estimate, Aggregate) protocol (Hemming *et al.* 2018). Expert elicitation took place from December 2020 to February 2021. Expert panels comprised up to 10 experts each (birds (10), mammals (9), frogs (10), reptiles (9), fish (8), spiny crayfish (7)). Six experts were each involved in the assessments for two taxonomic groups.

For each species we provided experts with summaries of the pre-fire population status, population trend and distribution information, trait information, and the management actions that are currently, or could be, implemented. Experts were invited to update those summaries prior to the elicitation, and updates were shared with the expert group. This process did not consider the extent of species' overlap with fire, but rather was used to predict the site-level population impacts of fires of varying severity.

Step 1: Investigate

We aimed to assess relative change, so we asked experts to assume a starting population of 100 individuals for each species, and then to estimate the proportional population change:

- after fires of different severity ('mild' (low/moderate), and 'severe' (high/very high) and when habitat was not burnt;
- at three time intervals (immediately after fire (up to one week), one year after, and projected forward to 10 years or three generations (whichever was longer) after the fire; and
- for three management scenarios (no management, current management, and all realistic actions implemented).

We asked experts to assume the following:

- The individuals occurred in a patch of 'typical' habitat for the species, representing typical land use history, topography, rainfall, and fire history.
- Within this patch (size undefined), the whole patch burnt in either a mild fire, or in a severe fire (we provided photos to illustrate these fire severity classes), or it remained unburnt. For aquatic species, we included comparable descriptions of post-fire sedimentation impacts.
- If the patch burned, the extent of the fire, and therefore the status of the broader landscape around the patch, was unknown; this was factored into the uncertainty of estimates. The 'unburnt' scenario assumed the surrounding landscape was also unburnt (this was essentially the control population).
- After the fire, the conditions were more or less normal, and there were no further extreme drought or fire events of the same magnitude as 2019–20 for the next 10 years/three generations, (whichever is longer). We recognise this may be unrealistic, especially for long-lived species, but we aimed to gauge how quickly populations could recover, under conditions that we are familiar with.

For each of the 27 possible combinations of fire severity, timeframe and management scenario, experts were asked to provide four judgements:

- The lowest plausible estimate for the number of individuals (relative to the pre-fire baseline of 100 individuals) found within the patch
- The highest plausible estimate for the number of individuals found within the patch
- The most plausible estimate for the number of individuals found within the patch
- Their confidence that the interval provided, from lowest to highest, captured the true number of individuals. This number should lie between 50 and 100%.

Birds and mammals include some species that are capable of fleeing fire fronts and living elsewhere for weeks, months or even years before habitat quality on the burnt patch recovers sufficiently for it to be used again. Examples include dispersive species like flying-foxes or some large parrots. Thus, the number of animals in the patch after fire may differ from the number of animals that survived the fire. We asked bird and mammal experts to provide an additional set of judgements on the number of animals that fled the patch ("escapees"), but were still alive and living elsewhere, immediately after the fire. Experts again provided their most plausible estimate, lower and upper bounds, and their confidence that the true value lay between those bounds.

Experts entered their answers into an Excel spreadsheet that included a self-populating graph to visualize the population changes over time for every fire severity, timeframe and management combination. Experts were asked to complete the first round of answers independently of other experts in their taxonomic group, but to use whatever information they had access to. Individual expert names were replaced with pseudonyms on each spreadsheet, and this anonymity was maintained throughout the elicitation process.

For each species, the project team then generated summaries of the population change over time, with confidence bounds (standardised to 80%, see below) for each fire severity and management scenario. The team also generated plots that displayed the variability in the post-fire population estimates and management dividends among elicitors and among species.

Step 2: Discuss

The aggregated summaries for each taxonomic group were provided back to the experts, and the experts then participated in a facilitated discussion via teleconference. The group clarified the information provided, discussed the aggregated results, identified any major discrepancies or inadvertent errors in the data, and introduced any further relevant information. The purpose of the discussion was not to reach consensus, but to resolve any linguistic ambiguity, promote critical thinking, and to share evidence (Hemming *et al.* 2018). This is based on research that suggests that including a discussion stage as part of an elicitation exercise can generate improvements in response accuracy (McBride *et al.* 2012).

Step 3: Estimate

After the discussion, experts were given the opportunity to revise their estimates.

Step 4: Aggregate

The project team again aggregated the data for each species. The project team assessed all estimates and contacted individual experts if apparent mistakes were made (for example, where the lowest plausible estimate was higher than the most plausible estimate).

Each expert's lowest and highest bounds were standardised to 80%, to bring the uncertainty of all experts into a consistent scale.

$$\text{lower standardised interval: } LSI = P - ((P - L) \times (80 / C))$$

$$\text{upper standardised interval: } USI = P + ((U - P) \times (80 / C))$$

Where P = most plausible estimate for the population, L = lowest plausible estimate, U = highest plausible estimate, and C = level of confidence given by the expert. In cases where the adjusted estimates fell outside of reasonable bounds (e.g. where values < 0) the data were truncated.

The most plausible estimates, standardised lower and upper bounds from each expert were then averaged for each species, at each of the 27 combinations of fire severity, timeframe and management scenario.

To estimate mortality caused by the fire in birds and mammals, we added each expert's estimate for the number of escapees to their most plausible, highest and lowest estimates for the number of fire-survivors still in the habitat patch.

The estimates for population change after no fire, mild fire, and severe fire, given the current management conditions, are key inputs for subsequent analyses in this section of the report. We used the expert judgements for the current management scenario, because the primary purpose was to provide information useful for conservation assessments.

Combining expert elicitation results with spatial analyses to estimate overall population changes

For each species, we multiplied the population estimates (the average best estimate, and the average 80% confidence bounds) at each timeframe, with the proportion of the species' distribution exposed to each of the three fire (or aquatic) impact states (none, mild, severe), to generate an overall population estimate for before the fire, to immediately after the fire, then out to 1 year and then 10 years/three generations after the fire. The overall population estimate was calculated for the scenario that assumed current management conditions.

Best estimate for the overall population immediately after fire:

$$OP_{immed} = (U \times P_{ub\_immed}) + (M \times P_{mild\_immed}) + (S \times P_{severe\text{-}immed})$$

Best estimate for the overall population 1 year after fire:

$$OP_{1yr} = (U \times P_{ub\_1yr}) + (M \times P_{mild\_1yr}) + (S \times P_{severe\_1yr})$$

Best estimate for the overall population 10 years after fire:

$$OP_{10yrs} = (U \times P_{ub\_10yrs}) + (M \times P_{mild\_10yrs}) + (S \times P_{severe\_10yrs})$$

Where U, M and S are the proportions of the distribution that are unburnt, burnt in a mild fire, and in a severe fire, respectively. They sum to 100.

P_{ub} is the population size in an unburnt patch; P_{mild} is the population size in a mildly burnt patch; P_{severe} is the population size in a severely burnt patch.

The upper and lower bounds for population decline were calculated using similar equations, but substituting the average LSI and USI values for P, in each timeframe.

Note that this approach assumes that density is even across the range of the species. The approach could underestimate (or overestimate) the overall population loss if the 2019–20 fires disproportionately burnt the higher quality (or lower quality) parts of a species' distribution.

Conservation status review

We follow the IUCN Red List guidelines (IUCN Standards and Petitions Committee 2019), and consider the population losses caused by fire assessable under Criterion A. Species occurring in fire-prone habitats could experience substantial mortality at regular intervals, and thus have a fluctuating population. The fluctuations would either need to be accounted for in estimates of overall population change, or the fluctuations could be considered extreme (and thus considered as part of Criteria B or C) if the difference between unburnt and recently burnt population sizes varies by an order of magnitude. However, Criterion A is more appropriate where such population losses following fire are highly unusual, as was the case in 2019–20. Criterion A1 would be relevant were further fires highly unlikely, but this assumption cannot be met given climate change trends. Instead, Criteria A2 (past decline), A3 (future decline) and A4 past and future decline) are more relevant for conservation assessments of taxa affected by the 2019–20 fires, with the relevant thresholds being >80% (Critically Endangered), 50%-80% (Endangered), and 30%-50% (Vulnerable) population reduction.

Species with extents of occurrence or areas of occupancy that are limited (i.e. less than 20,000 km^2 and 2000 km^2 respectively) may qualify for listing under Criterion B if the fire impacts cause population loss that seems likely to continue, for example because the taxon is long-lived and another large-scale fire event is expected to affect it within three generations. Similarly, if a taxon's population size was limited (i.e. < 10,000), it may be eligible under Criterion C if the fire-initiated decline seems likely to continue. Finally, if the fires have pushed the population size below 1000, the taxon may be eligible under Criterion D.

Fire-caused population loss should also be considered in the context of the conservation status and trend of each taxon leading up to the 2019–20 fires, and if the taxon was already recognised as threatened, the criterion against which it was listed. For example, if a taxon was already listed as Vulnerable due to an overall population decline of 40%, then a fire-induced population loss of just 20% would be enough to push the taxon into the Endangered category, whereas a 20% decline in a species with a pre-fire population that was stable may not precipitate a change in listing status against Criterion A (although it could make the taxon eligible for listing under other criteria, depending on the specifics).

The EPBC Act may not have accurately reflected the true, pre-fire conservation status of each taxon in the assessment; however, by comparing our estimates of the fire impacts on each taxon against the current conservation status and information across the EPBC Act, the IUCN Red List, Action Plans and other expert assessments, we can suggest which taxa warrant assessment or re-assessment, regardless of whether the pre-fire status on the EPBC Act list was correct or not.

Results and discussion

The results are presented for each taxonomic group separately, followed by a section that compares the results across the taxonomic groups. Common names are used as the primary identifier for birds and mammals, while scientific names are used in the other taxonomic groups. Note that we use 'species' unless we are referring to subspecies or both species and subspecies, in which case we use 'taxa'.

Birds - summary

- 68 taxa (54 species) were included in the spatial analysis based on preliminary screening that indicated that fire may have overlapped with their distribution by > 10% if listed, and > 25% if not listed.
  - The taxon with the largest fire overlap (68%) was the Kangaroo Island Southern Emu-wren, *Stipiturus malachurus halmaturinus.*
  - The taxon with the largest severe fire overlap of 57% was again the Kangaroo Island Southern Emu-wren.
- We carried out expert elicitation to estimate the local population response to no, mild and severe fires for 28 taxa from 19 species.
  - The taxa with the most extreme predicted local population decline when exposed to severe fire were the Kangaroo Island Southern Emu-wren, the Southern Yellow-throated Scrubwren *Sericornis citreogularis citreogularis*, the Red-browed Treecreeper *Climacteris erythrops*, and the Albert's Lyrebird *Menura alberti*. These tend to be birds with limited dispersal abilities or that live in habitats rarely exposed to fire.
  - Conversely, taxa with the smallest predicted local population declines when exposed to severe fire were highly mobile birds such as Kangaroo Island Glossy Black-Cockatoo *Calyptorhynchus lathami halmaturinus*, Latham's Snipe *Gallinago hardwickii*, and the Regent Honeyeater *Anthochaera phrygia*.
  - Uncertainty about the local population response increased with increasing time since fire, and was generally greater for the severe fire scenario than the mild or no fire scenarios.
- We combined the estimates for the proportions of each taxon's distribution affected by each fire class with the expert estimates for local proportional population change after fires of varying severity (assuming conditions of current management) to derive estimates of the overall population change in each taxon.
  - The taxon with the largest mean estimate for population decline after fire was the Kangaroo Island Southern Emu-wren, at 51% reduction one week after fire, and 56% reduction one year after fire. By 10 years/three generations post fire, the Northern Rufous Scrub-bird *Atrichornis rufescens rufescens* was predicted to have the largest decline (38%).
  - In all taxa, the extent of population decline increased from one week to one year after fire, reflecting expert opinion about continued high mortality in the post-fire environment.
  - In 10 taxa, the mean estimate for the overall population size is similar or decreases between one year, and 10 years/three generations post-fire, indicating poor recovery or continuing decline (e.g. Rufous Scrub-bird (both subspecies), Gang-gang Cockatoo *Callocephalon fimbriatum*, Western Bassian Thrush *Zoothera lunulata halmaturina*).
  - In 20 taxa, population size may recover, to some extent, between one year and 10 years/three generations, in that the 80% confidence bounds around the population estimate at 10 years/three generations included zero (i.e. recovery to pre-fire population size is plausible). However, only four taxa (two species) had mean estimates for the population size that were close to zero (i.e. within 5%; the Kangaroo Island Glassy Black-Cockatoo, which is the subject of intensive management intervention; and the Eastern Bristlebird *Dasyornis brachypterus* and its two subspecies, which experienced small fire overlaps relative to other taxa).
  - The long-term 'legacy' effects of the fire were predicted to be greatest for the Kangaroo Island Glossy-Black-Cockatoo and the Kangaroo Island Western Whipbird *Psophodes nigrogularis lashmari*. In both taxa, the population size after three generations is predicted to be 30% less than it would have been, had the fires not occurred.
- All the bird taxa in our assessment have experienced population declines as a result of the 2019–20 fires, but the extent of those declines, and the potential for population recovery, is variable. From reviewing the current conservation statuses in the EPBC Act, the IUCN Red List, and the Bird Action Plan (Garnett *et al.* 2011), and considering our estimates for population loss as a result of fire, we suggest that 20 to 24 previously unlisted bird taxa may be eligible for listing as nationally threatened, and one taxon already recognised as nationally threatened may be eligible for uplisting.
- The status of 10 taxa (six species) that are already listed under the EPBC Act has worsened, but either not sufficiently to meet thresholds for uplisting, or they are already listed as CR.
- We stress that for a thorough conservation assessment, our estimates for population declines and fire impacts should be considered in the context of other information on past and future predicted population trajectories, and threat status, for each taxon. Ideally, surveys should be undertaken to provide field data on population status across the range of each taxon, in both fire-affected areas and locations not affected by the 2019–20 fires.

Birds - spatial overlaps of fire with distributions

Of the 68 bird taxa (four with alternative seasonal distributions) in this analysis, the proportion of a taxon's distribution that was burnt varied up to a maximum of 68%, for the Kangaroo Island Southern Emu-wren (Fig. 4; Appendix 1a). This taxon also had the largest value for the proportion of its distribution burnt in a severe fire (57%).

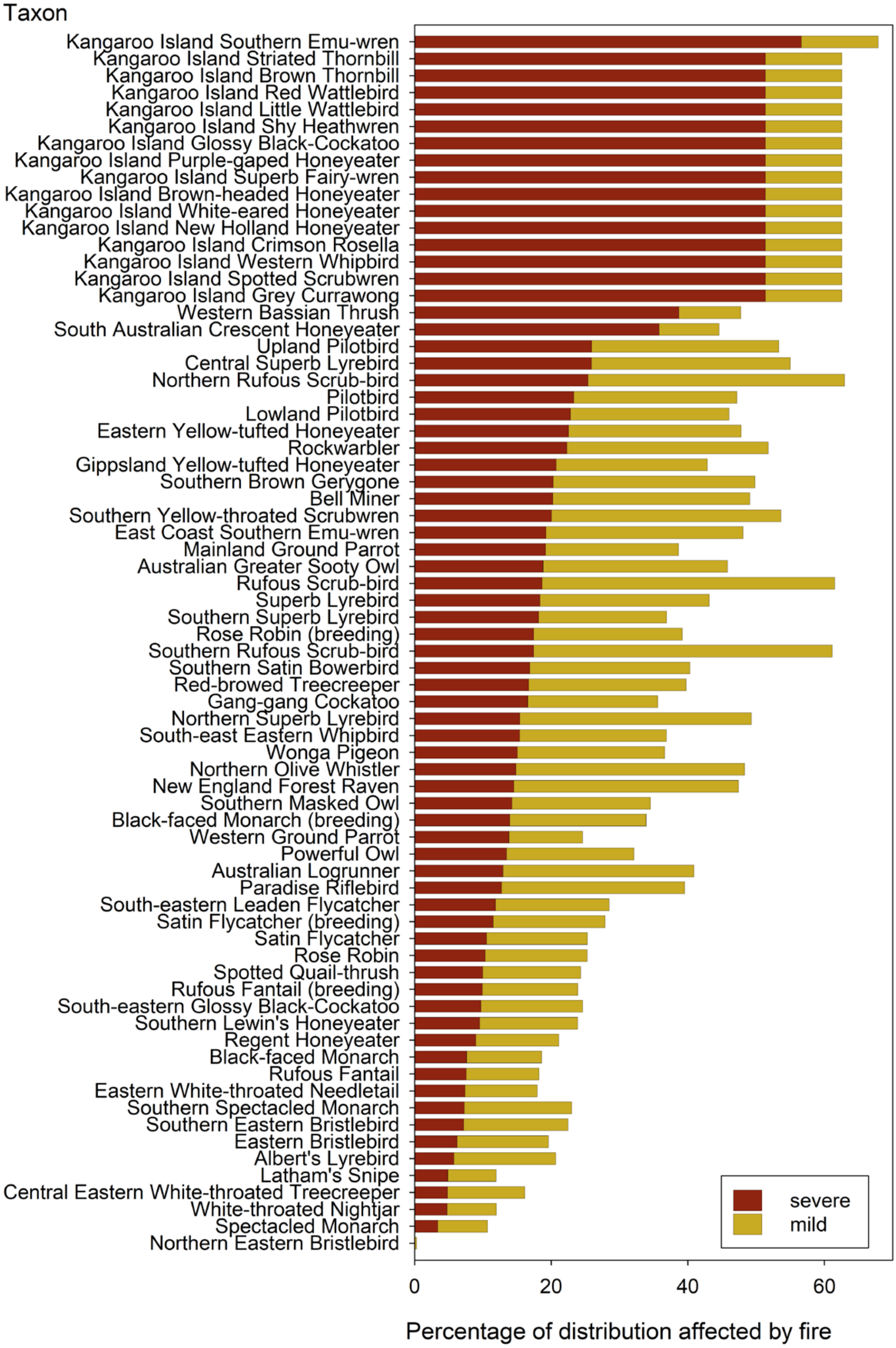


Fig. 4. The proportions of distributional overlap with the extents of severe and mild fire for 68 bird taxa, four with alternative seasonal distributions. Species and constituent subspecies are displayed separately. The group of 16 birds at the top of the graph from Kangaroo Island have overlapping distributions, and thus similar estimates for distributional overlaps with fire.

The distribution of fire extent values was bimodal (Fig. 5), driven by a peak in severe fire extent values for a cluster of taxa with similar fire overlap estimates from Kangaroo Island, where the 2019–20 fires were severe across a large proportion of the landscape.

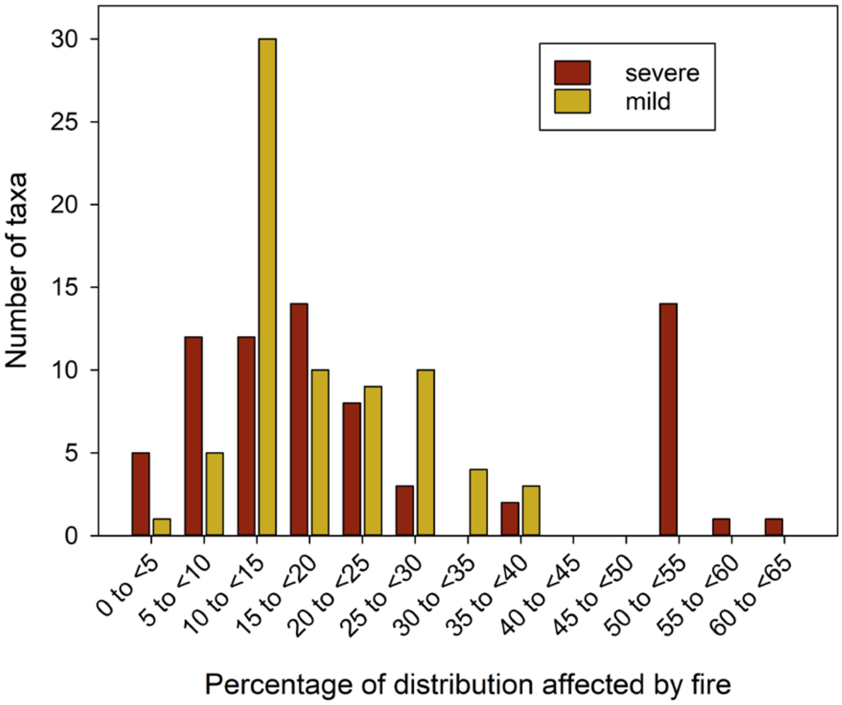


Fig. 5. *The distribution of fire overlap proportions across 68 bird taxa (three with alternative seasonal distributions), displayed for severe and mild fire separately.*

Birds – expert estimates of local population response to fires of varying severity

Of the 68 bird taxa included in the spatial analyses (four with two seasonal distributions), expert elicitation on the local population response to fires of different severity were carried out for 28 taxa from 19 species; these were taxa with a range of mostly high fire overlap values and those with poor conservation status.

The expert judgements on each taxon's local population change, in the event of no fire, mild fire and severe fire, from just after the fire (one week), at one year post-fire, and 10 years/three generations post-fire, are summarised in Fig. 6. Taxa near the bottom of the left-hand panel, including Albert's Lyrebird and the Kangaroo Island Southern Emu-wren, are those that experts considered are most heavily impacted by severe fire, experiencing immediate population losses of 70-80%. In contrast, taxa near the top of the graph, such as the Kangaroo Island Glossy Black Cockatoo, Latham's Snipe, and the Regent Honeyeater are those that experts considered were less immediately impacted by severe fire. These are highly mobile taxa, and considered to be better able to flee fire fronts.

The second panel, which summarises the population changes at one year after fire, shows that the ordering of taxa in terms of relative fire impacts, is mostly similar to the first panel. However, the size of population loss has generally increased, reflecting expert opinion that mortality rates in the year after fire are elevated for many taxa, including for the mobile taxa near the top of the panel that escaped some of the immediate effects of fire. By 10 years/three generations, taxa were re-ordered, and the relative differences between populations exposed to mild fire, severe fire, or no fire, were still evident, but had diminished. Of all the taxa included in the elicitation, only the KI Glossy Black Cockatoo seems likely to recover to its pre-fire population size, across all three fire scenarios, reflecting high management input for this taxon. Uncertainty about the local population response increased with increasing time since fire, and was greater for the severe fire scenario than the mild or no fire scenarios. Uncertainty was particularly high for the 10 year/three generation estimates for the Kangaroo Island Glossy Black-Cockatoo, in the no fire scenario, again related to the high reliance on management input to sustain population persistence (Fig. 6, and see section on Uncertainty overleaf).

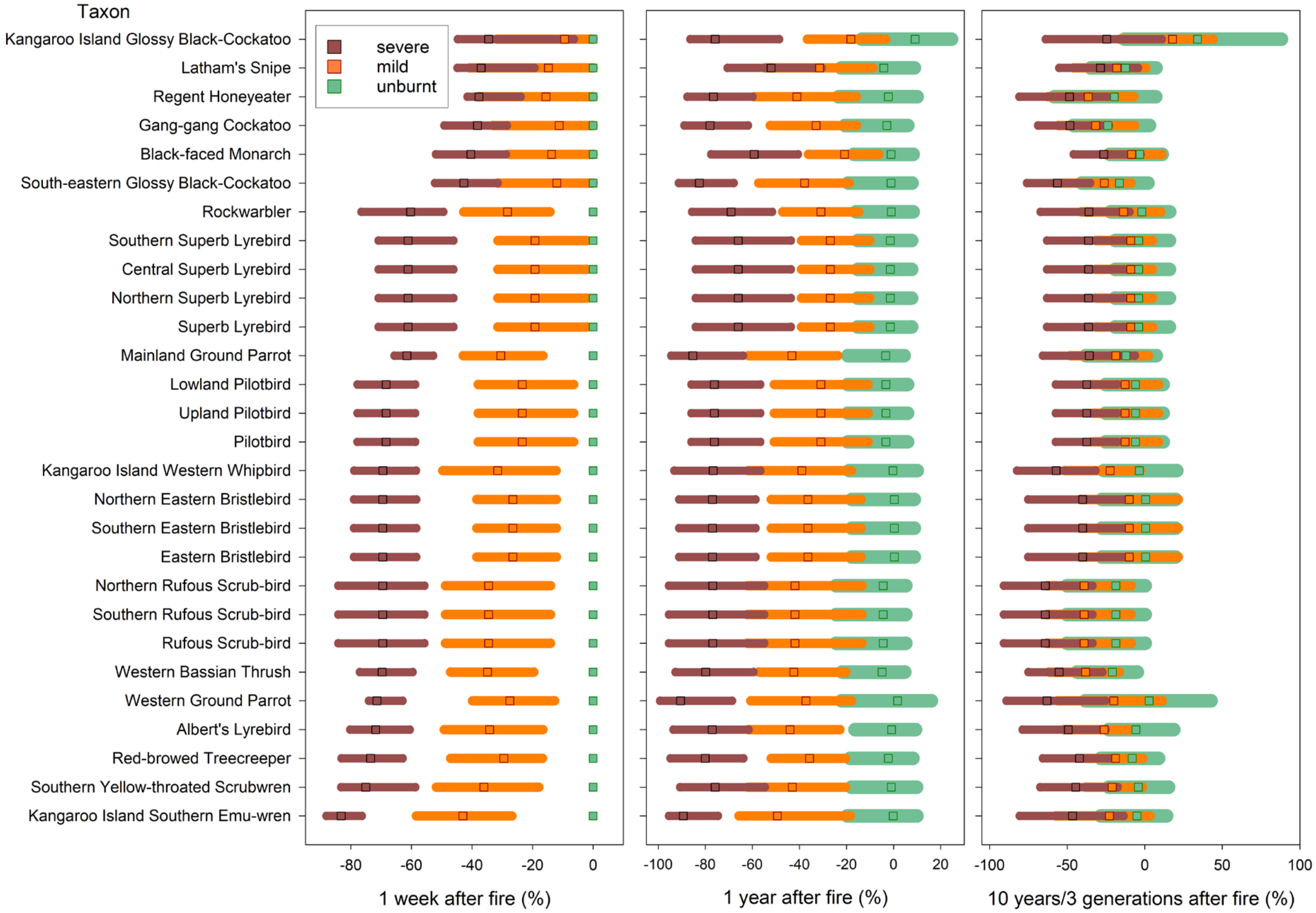


Fig. 6. *The expert judgements on the population changes after severe fire, mild fire, and no fire, from just before the fire, to 1 week, 1 year, then 10 years/3 generations (whichever is longer) after the fire. Each bar shows the plausible estimate and the 80% confidence bounds, averaged across experts.*

Birds – estimated overall population decline for each species

The expert estimates for proportional population change after fires of varying severity, assuming conditions of current management, were combined with the estimates for the proportions of each taxon's distribution affected by each fire class to derive estimates of the overall population change in each taxon. The effects of management, including enhanced management, on population change are explored in a companion report.

The estimates for the overall population change in these taxa, at three time points after fire, are shown in Fig. 7. In these estimates of population change, the proportion of birds in burnt patches that escaped the fire by fleeing the hypothetical habitat patch have been added to the proportion that survive the fire and remain in situ. By one year, some of these escapees will have died (e.g. from lack of alternative habitat), some may have returned to the habitat patch, and some may still survive off-patch; the estimates presented here omit the unknown proportion of birds still surviving off-patch at one year, but we note this is likely to make a small difference to overall population estimates. By ten years, we assume that escapees are likely either dead or have returned to their original habitat patch.

The estimates for overall population decline immediately after the fire average 18% across all 28 taxa for which elicitation was conducted; and range from close to zero for Northern Eastern Bristlebirds to a 51% reduction for Kangaroo Island Southern Emu-wrens (Fig. 7). By one year after fire, the population changes across all taxa averaged a 28% reduction, reflecting that in most species, the post-fire conditions cause ongoing mortality. For example, the Kangaroo Island Southern Emu-wren was again the taxon with the greatest overall population loss, this time with a 56% reduction. By ten years/three generations, the average overall decline was 17%, reflecting some predicted population recovery in at least some taxa. The taxon with the largest population decline by this time was the Northern Rufous Scrub-bird, with a 38% decline (Fig. 6). Inspection of the 80% confidence bounds suggest that seven species may be reduced by 50% one year post fire, and that eight species may be reduced by at least 50% by 10 years/three generations post fire. In general, the confidence bounds of estimated population changes for each taxon increased with time after fire (Fig. 7).

The population sizes may recover between one year and 10 years/three generations for 20 taxa, in that the 80% confidence bounds around the population estimate at 10 years/three generations included zero (i.e. recovery to pre-fire population size is plausible). However, only four taxa had mean estimates for population size change that were close to zero, meaning they have returned to their pre-fire populations size (the Kangaroo Island Glossy Black-Cockatoo, which is the subject of intensive management intervention; and the Eastern Bristlebird and its two subspecies, which experienced small fire overlaps relative to other taxa) (Fig. 7). In 10 taxa, the mean estimate for the overall population size is similar or decreases between one year, and 10 years/three generations post-fire, indicating poor recovery or continuing decline (e.g. Rufous Scrub-bird (both subspecies), Gang-gang Cockatoo, Western Bassian Thrush) (Fig. 8). Variation in post-fire recovery among species could reflect the time required for critical resources to re-establish, difference in management inputs and their effectiveness, or that the taxon is experiencing ongoing decline due to other threats.

To disentangle any legacy effects of fire on the longer-term population trajectory, we compared the estimates for the overall population change after fire to the estimates for population change in the unburnt scenario, for each taxon (Fig. 8). The differences between the predicted population changes at 10 years/three generations, with and without the 2019–20 fires, are summarised across taxa in Fig. 9. The taxa with the largest population deficit (by 25-30%) as a result of the 2019–20 fires are the Kangaroo Island Southern Emu-wren, Kangaroo Island Glossy Black-Cockatoo, and Kangaroo Island Western Whipbird, all endemic to Kangaroo Island; followed by Rufous Scrub-bird (both subspecies), and Western Bassian Thrush (with 20-30% deficits). Note that the expert judgements on the population change after fire included an assumption of no further large-scale fires. However, projections of future climate and fire risk suggests that this is unrealistic (Williams *et al.* 2009; Di Virgilio *et al.* 2019), so the population recovery estimates are optimistic, especially for long-lived bird taxa.

If fire class 2 was grouped with unburnt, rather than with mild fire, the average population decline was reduced by 2.1%, 2.7% and 1.1% immediately, 1 year, and 10 years/three generations after fire respectively. Only three taxa (one species) had population declines that exceeded 5% in any time period: the Rufous Scrub-bird (and its two subspecies) had population declines of 6.3-8.7% greater immediately after, and at one year post fire, when fire class 2 was classed as mildly burnt, compared to when it was classed as unburnt.

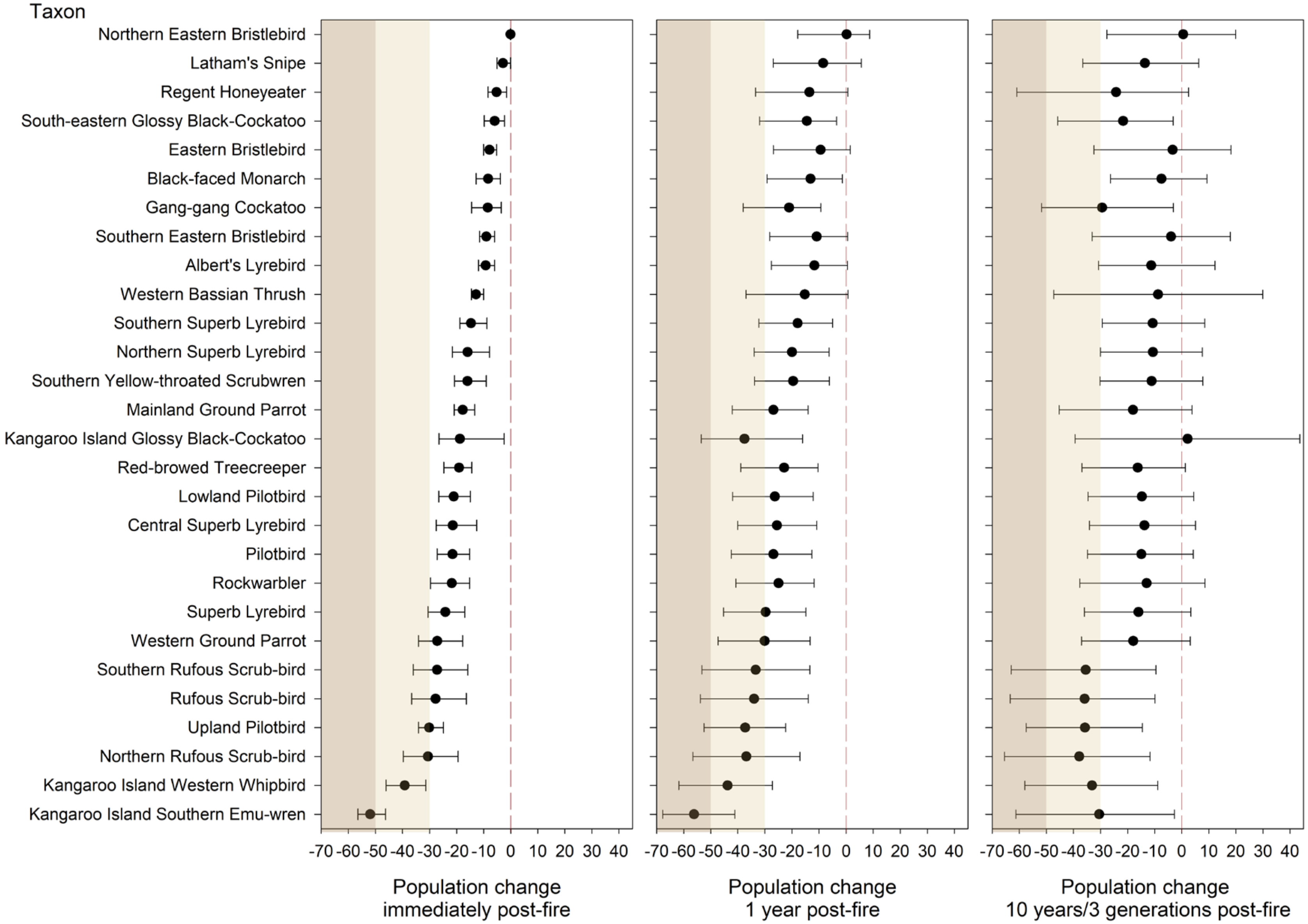
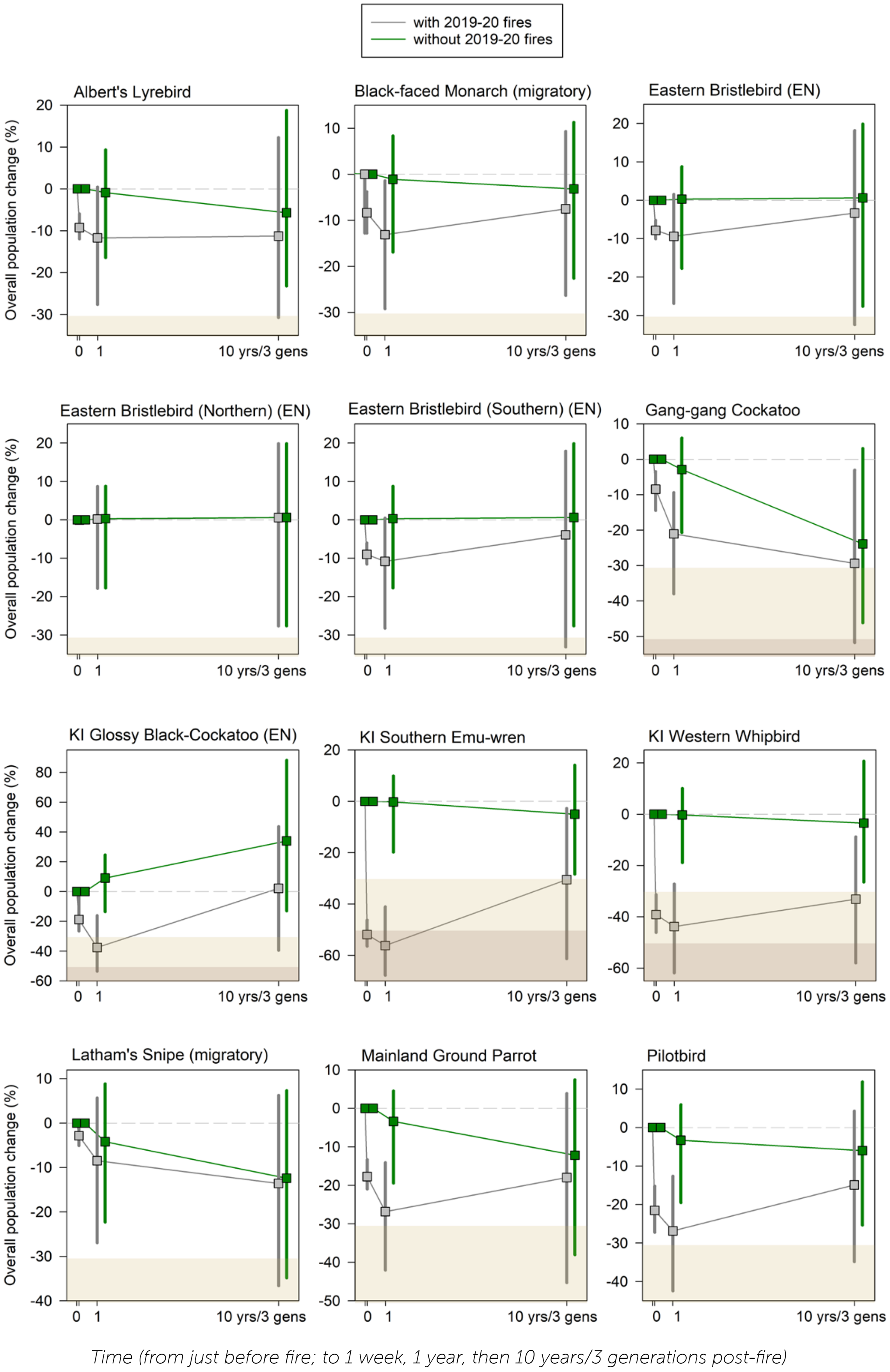
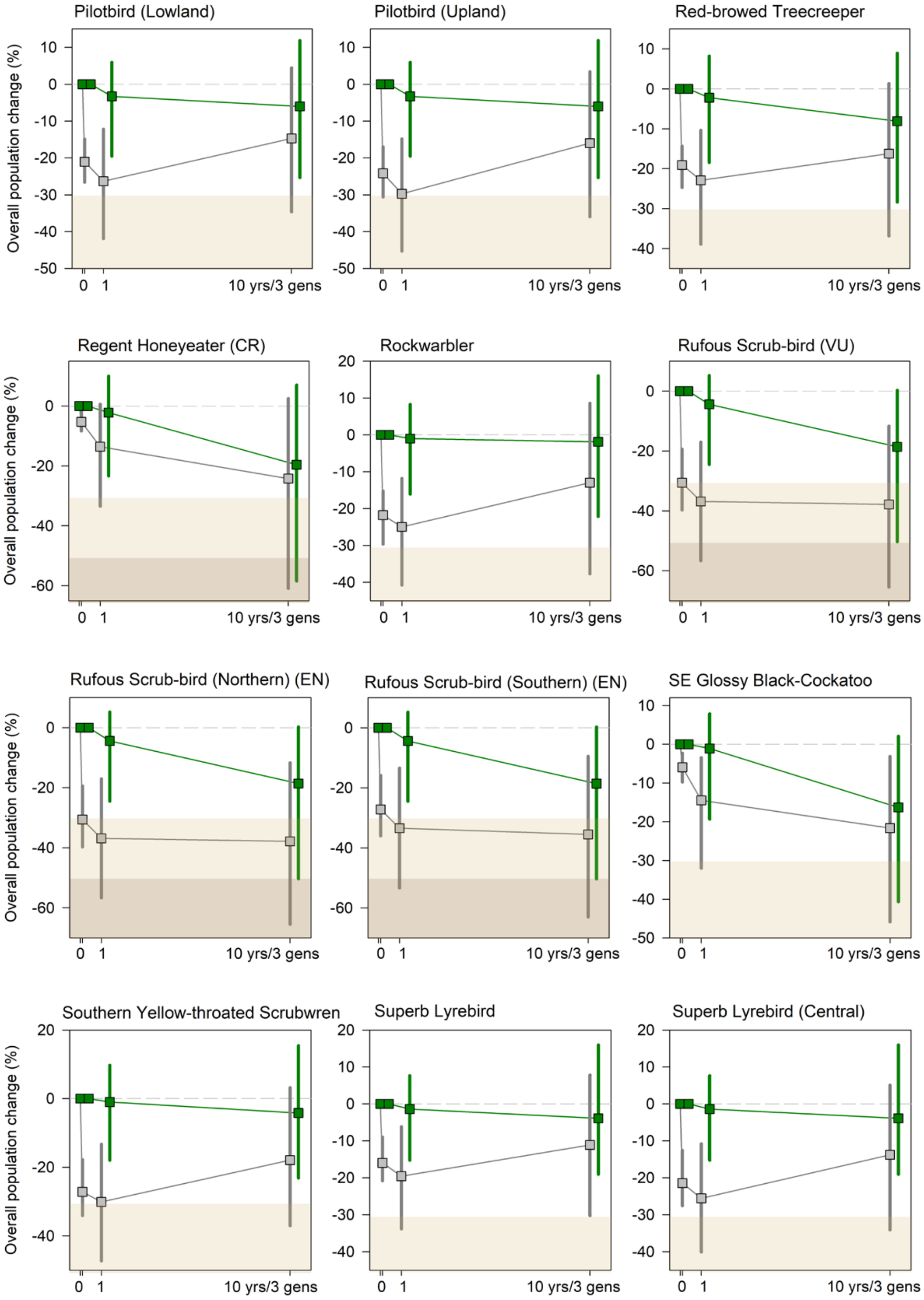


Fig. 7. The overall population change in 28 bird taxa, 1 week, 1 year and 10 years/three generations after the 2019–20 fires. Taxa are arranged in order of increasing population decline immediately after fire. The estimates are based on combining expert judgement on population response to fires of different severity, with spatial analysis of the proportion of each taxon's range affected by fires of each severity. The graphs show the average estimates and 80% confidence bounds across the expert judgements. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%).

Fig. 8. (next 3 pages) *Changes in overall population size for each taxon, given the 2019–20 fires (grey lines), and if the fires had not occurred (green lines). Population changes are based on the expert judgements of how each taxon responds to fires of varying severity, combined with the spatial analyses of the proportions of each taxon's range that overlapped with fires of varying severity. Data represent the average estimate and 80% confidence bounds across experts. Both population responses assume no further large-scale fire within the 10 year/3 generation period. Species are arranged alphabetically by common name. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%).*





Pilotbird (Lowland)

Pilotbird (Upland)

Red-browed Treecreeper

Regent Honeyeater (CR)

Rockwarbler

Rufous Scrub-bird (VU)

Rufous Scrub-bird (Northern) (EN)

Rufous Scrub-bird (Southern) (EN)

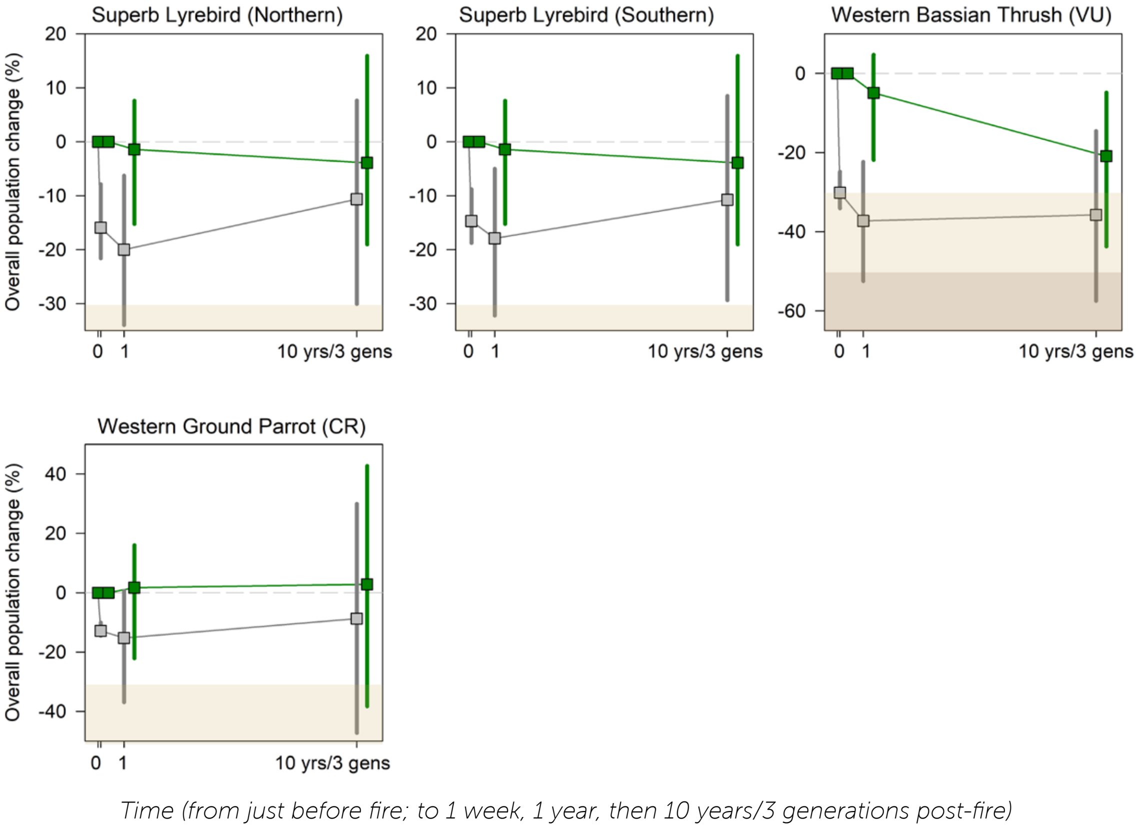
SE Glossy Black-Cockatoo

Southern Yellow-throated Scrubwren

Superb Lyrebird

Superb Lyrebird (Central)

Time (from just before fire; to 1 week, 1 year, then 10 years/3 generations post-fire)



Western ground parrot (Pezoporus wallicus flaviventris). *Image: Brent Barrett CC BY-SA 2.0 Wikimedia Commons*

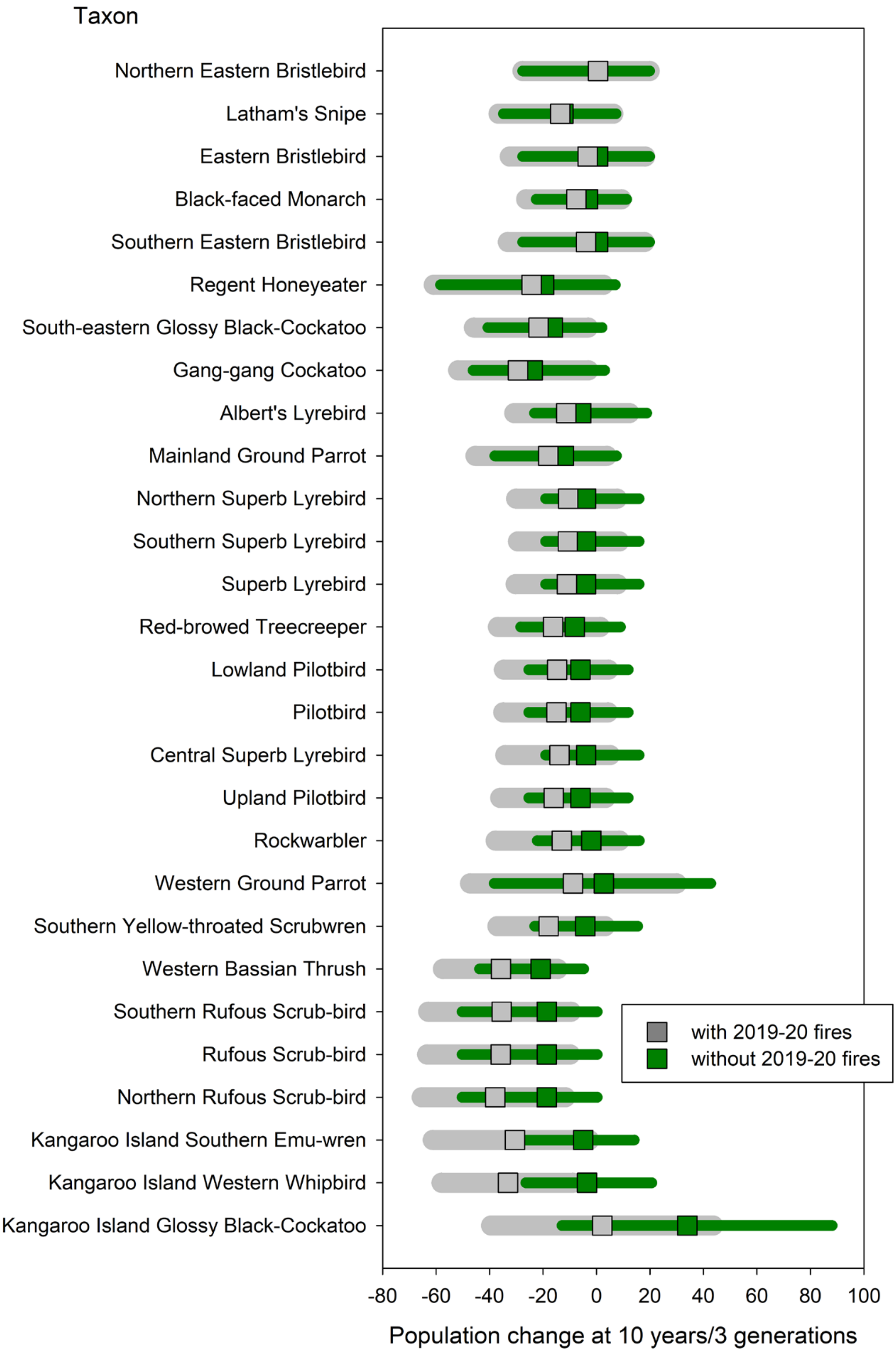


Fig. 9. The legacy effects of the 2019–20 fires, 10 years/three generations later. The graph shows the predicted population change, with 80% confidence bounds, for each taxon given the 2019–20 fires (grey), and if the fires had not occurred (green). Species are sorted on this graph by the magnitude of the legacy effects of fire: these are greater in taxa near the bottom of the graph, where the differences in predictions for overall population change between burnt and unburnt scenarios are largest.

Birds – priorities for conservation status review

All of the 68 bird taxa considered in this assessment have experienced overall population declines of varying magnitude as a result of the 2019–20 fires; we estimated the population loss using an expert elicitation procedure for 28 of these taxa. The elicitation showed that taxa may partially recover over 10 years/three generations, but they will still have smaller populations relative to the size they could have been, had the fires not occurred (Figs. 8, 9). In addition, these predictions assume no further extensive fire events, but climate modelling suggests periods of extreme fire weather will become increasingly common (Williams *et al.* 2009; Di Virgilio *et al.* 2019). Thus, the predictions are likely underestimates, especially for long-lived bird taxa. Recurrent fires that occur before full recovery has occurred will culminate in a progressive downward population trajectory.

We reviewed the estimated population change immediately after fire, at one and 10 years/three generations for all 28 taxa included in the expert elicitation, and their current conservation status under the EPBC Act, as well as in the Bird Action Plan (Garnett *et al.* 2011), and on the IUCN Red List. We focussed on the most plausible estimates and the lowest 80% confidence bound for the population loss, to develop these guidelines:

- If the taxon is already listed as CR, it cannot be uplisted because it is already in the highest category of endangerment.
- If the most plausible predicted estimate for population loss in any time period exceeds a relevant threshold that would cause the taxon to be listed or uplisted under Criterion A (30% if the taxon is currently unlisted; 50% if currently listed as VU; 80% if currently listed as EN), we recommend the taxon be assessed/re-assessed.
- If the predicted population decline approaches a relevant threshold (i.e. the plausible bounds include the threshold but the most plausible estimate does not exceed it), then:
    - If the taxon is listed (or listed in a higher category) by Garnett *et al.* (2011) or by the IUCN Red List, but not by the EPBC Act, then this suggests there is evidence of decline additional to the substantial impacts of the 2019–20 fires, and the taxon should be assessed/re-assessed.
    - If the taxon is not listed, or not listed at a higher category, by Garnett *et al.* (2011) or by the IUCN Red List, assessment or re-assessment could still be warranted. For example, if the taxon has a restricted distribution or population size, and has experienced declines as a result of the fire which may continue (given increasing fire frequencies), then the taxon could be eligible for listing under Criteria B or C. This was reviewed case by case.

We also reviewed potential conservation status changes for taxa where we carried out spatial analysis of fire impacts, but did not elicit information on population response to fire (40 taxa). Of these 40 taxa, only one, the Eastern White-throated Needletail *Hirundapus caudacutus*, is currently listed as nationally threatened (VU). This species is a highly mobile aerial forager, and fire may affect it less than other taxa. The fire overlaps for this taxon are relatively low (18% overall, and 7% with severe fire), and unlikely to cause proportional population losses such that the Needletail would now be eligible for listing as Endangered. To consider whether listing assessment was warranted for the remaining 39 taxa, we first examined the relationship between predicted population declines and the fire distributional overlap in taxa for which we had elicited information on population fire response. The population change at one year had a close relationship to the proportion of a taxon's distribution that overlapped with the fire extent, particularly with the extent of severe fire (Fig. 10). These relationships were weaker by 10 years/three generations. Based on this information, we developed a guideline for the 39 taxa for which we only had fire overlap information:

- If the proportion of a taxon's distribution burnt in severe fire is greater than 50%, there is a reasonable chance that the overall population loss exceeds a threshold that would cause that taxon to be listed or uplisted, and we recommend the taxon be assessed.

Using these guidelines to review the conservation assessment priorities across 68 bird taxa, we consider that the 2019–20 fires have had impacts sufficient to cause 20 to 24 previously unlisted taxa to potentially be eligible for listing as nationally threatened, and to cause one taxon already recognised as nationally threatened to be eligible for uplisting (Fig. 11). Thirty-four taxa are unlikely to qualify for listing, and 10 threatened taxa are unlikely to qualify for uplisting (Fig. 11). For a full conservation assessment, our estimates for population declines and fire impacts will need to be considered in the context of other information on declines, and other information on past and future predicted population trajectories.

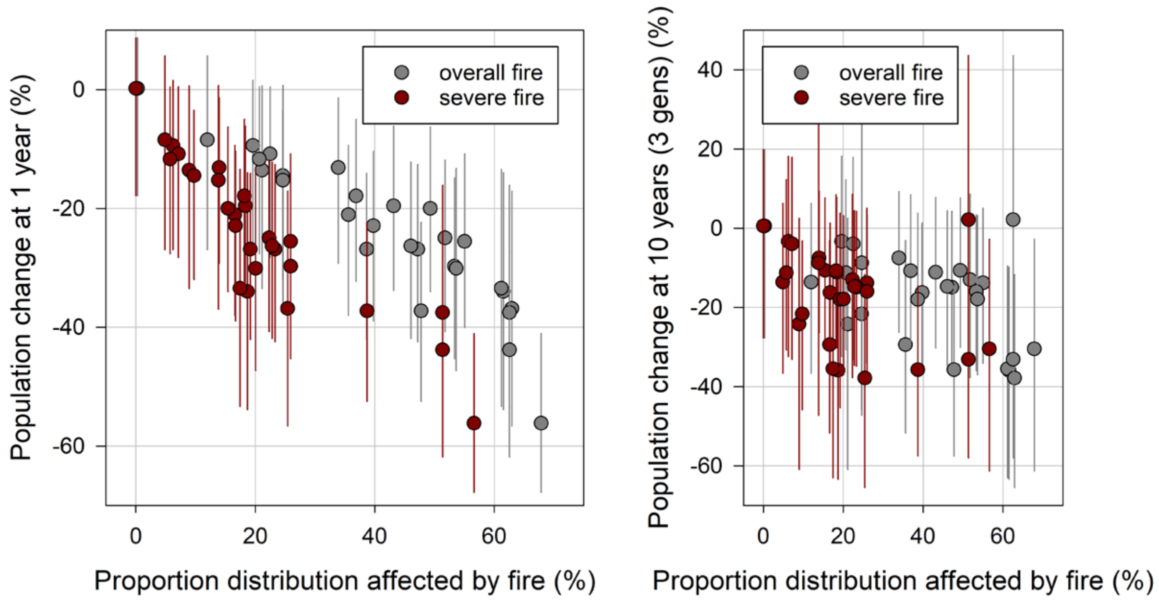
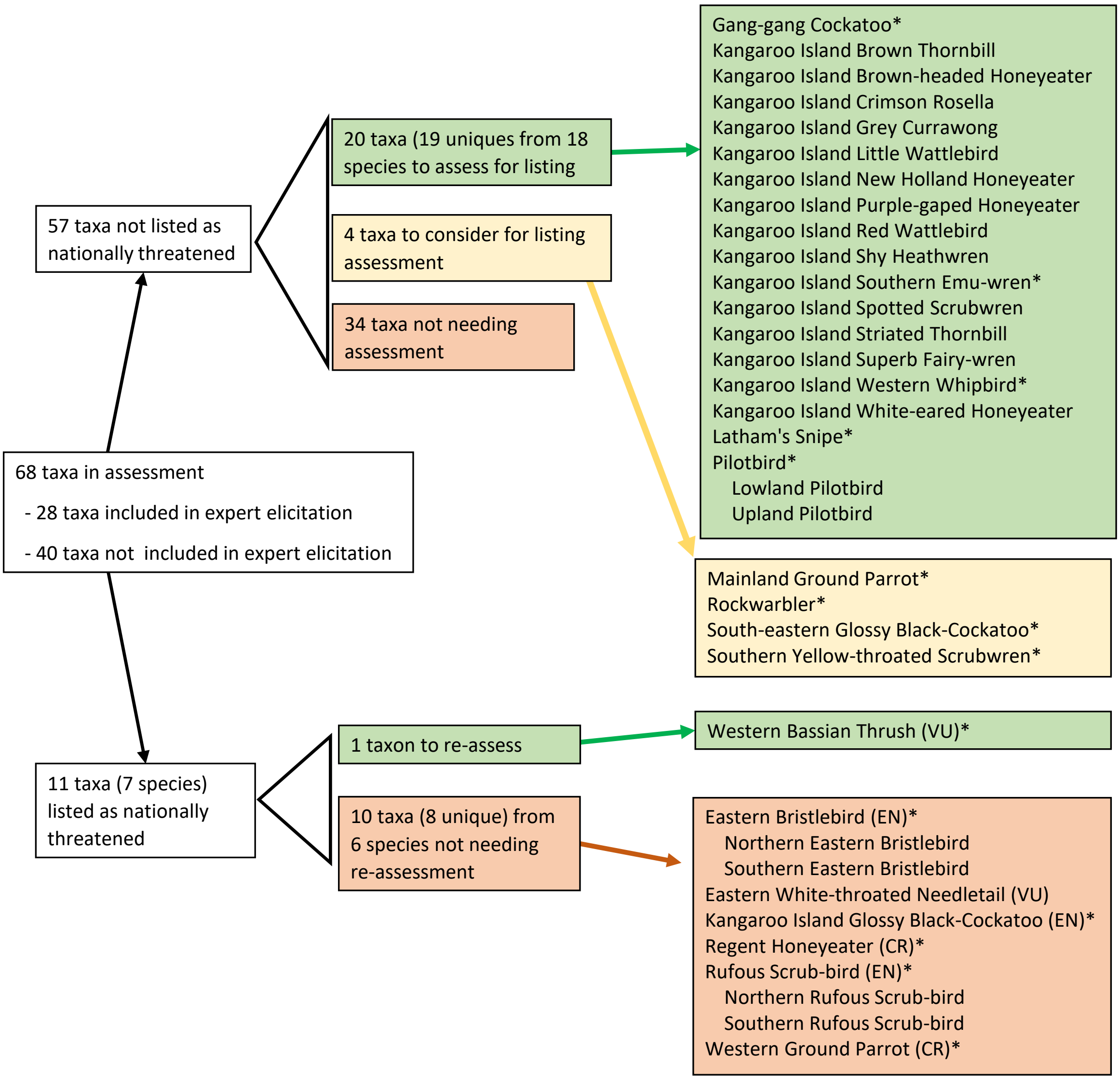


Fig. 10. The population change, as estimated by experts, for 28 bird taxa at 1 year (left), and at 10 years (right) against the proportions of their distributions that overlapped with the fire extent (grey) and with severe fires (brown).



68 taxa in assessment
- 28 taxa included in expert elicitation
- 40 taxa not included in expert elicitation

57 taxa not listed as nationally threatened

20 taxa (19 uniques from 18 species to assess for listing

4 taxa to consider for listing assessment

34 taxa not needing assessment

Gang-gang Cockatoo*
Kangaroo Island Brown Thornbill
Kangaroo Island Brown-headed Honeyeater
Kangaroo Island Crimson Rosella
Kangaroo Island Grey Currawong
Kangaroo Island Little Wattlebird
Kangaroo Island New Holland Honeyeater
Kangaroo Island Purple-gaped Honeyeater
Kangaroo Island Red Wattlebird
Kangaroo Island Shy Heathwren
Kangaroo Island Southern Emu-wren*
Kangaroo Island Spotted Scrubwren
Kangaroo Island Striated Thornbill
Kangaroo Island Superb Fairy-wren
Kangaroo Island Western Whipbird*
Kangaroo Island White-eared Honeyeater
Latham's Snipe*
Pilotbird*
    Lowland Pilotbird
    Upland Pilotbird

Mainland Ground Parrot*
Rockwarbler*
South-eastern Glossy Black-Cockatoo*
Southern Yellow-throated Scrubwren*

11 taxa (7 species) listed as nationally threatened

1 taxon to re-assess

10 taxa (8 unique) from 6 species not needing re-assessment

Western Bassian Thrush (VU)*

Eastern Bristlebird (EN)*
    Northern Eastern Bristlebird
    Southern Eastern Bristlebird
Eastern White-throated Needletail (VU)
Kangaroo Island Glossy Black-Cockatoo (EN)*
Regent Honeyeater (CR)*
Rufous Scrub-bird (EN)*
    Northern Rufous Scrub-bird
    Southern Rufous Scrub-bird
Western Ground Parrot (CR)*

Fig. 11. A summary of recommendations for conservation status assessments for birds. Names of taxa that warrant conservation status review are shown in green boxes, and those for which assessment should be considered are in yellow boxes. Species currently listed as threatened that are unlikely to qualify for uplisting are shown in the red box. Species included in the elicitation are noted with asterisks. The full list of taxa with reason for the recommendations is in Appendix 1a. Species included in the elicitation are marked with an asterisk.

Mammals - summary

- 56 taxa (46 species) were included in the spatial analysis based on preliminary screening that indicated that fire may have overlapped with their distribution by > 10% if listed, and > 25% if not listed.
  - The taxon with the largest fire overlap (95%) was the Kangaroo Island Dunnart, *Sminthopsis fuliginosus aitkeni*. This taxon also had the largest value for the proportion of its distribution burnt in a severe fire (90%).
  - Another Kangaroo Island endemic, the Kangaroo Island Echidna *Tachyglossus aculeatus multiaculeatus*, was second-ranked in terms of its overlap with severe fire (53%).
  - On the mainland, the taxon with the largest distributional overlap with fire, at 80%, was the Long-footed Potoroo, *Potorous longipes*, with 38% being burnt severely.
- We carried out expert elicitation to estimate the local population response to no, mild and severe fires for 43 taxa from 34 species.
  - The taxa with the most extreme local population decline when exposed to severe fire were assessed to be Greater Glider *Petauroides volans* (both subspecies), Yellow-bellied Glider *Petaurus australis*, Mainland Dusky Antechinus *Antechinus mimetes*, and Koala *Phascolarctos cinereus*, with predicted immediate population losses of over 75%, with the 80% confidence bounds approaching 100%.
  - Conversely, taxa that experienced the smallest local population declines when exposed to severe fire were assessed to be the Eastern Horseshoe Bat *Rhinolophus megaphyllus* which roosts in fire-proof caves, and the Platypus *Ornithorhynchus anatinus*, which can shelter in its burrow or in water.
  - Uncertainty about the local population response increased with increasing time since fire, and was greater for the severe fire scenario than the mild or no fire scenarios.
- We combined the estimates for the proportions of each taxon's distribution affected by each fire class with the expert estimates for local proportional population change after fires of varying severity (assuming conditions of current management) to derive estimates of the overall population change in each taxon.
  - The taxon with the largest mean estimate for population decline after fire was the Kangaroo Island Dunnart, with 65% reduction one week and also at one year after fire. By 10 years after fire, the Kangaroo Island Dunnart population was predicted to be 46% less that its pre-fire size, making it again the most impacted taxon at this time.
  - In all taxa, the extent of population decline increased between one week and one year after fire, reflecting experts' opinions about continued high mortality in the post-fire environment.
  - In 25 taxa, the mean estimate for the overall population size is very similar or decreases between one year, and 10 years/three generations post-fire, indicating poor recovery or continuing decline (e.g. Greater Glider (both subspecies), Koala, Long-nosed Potoroo *Potorous tridactylus* (mainland) (and both subspecies), and Yellow-bellied Glider.
  - In 16 taxa, population size may recover, to some extent, between one year and 10 years/three generations, in that the 80% confidence bounds around the population estimate at 10 years/three generations included zero (i.e. recovery to pre-fire population size is plausible). However, in no cases did the mean estimate for the population size at 10 years/three generation exceed, or was close to, zero (i.e. there are none with populations within 5% of zero).
  - The long-term 'legacy' effects of the fire were predicted to be greatest for the Kangaroo Island Dunnart, the two species of Potoroo *Potorous* spp. and the Hastings River Mouse *Pseudomys oralis*. In these taxa, the population size after three generations was predicted to be up to 40% less than it would have been, had the fires not occurred.
- All the mammal taxa in our assessment have experienced population declines as a result of the 2019–20 fires, but the extent of those declines, and the potential for population recovery, is variable. From reviewing the current conservation status in the EPBC Act, the IUCN Red List, and the Mammal Action Plan, and considering our estimates for population loss as a result of fire, we propose that one to five previously unlisted mammal taxa is eligible for listing as nationally threatened, and nine to 13 taxa already recognised as nationally threatened are eligible for uplisting.
- The status of seven taxa (five species) that are already listed under the EPBC Act has worsened, but either not sufficiently to warrant uplisting, or they are already listed as CR.
- We stress that for a thorough conservation assessment, our estimates for population declines and fire impacts need to be considered in the context of other information on past and future population trajectories, and threat status, for each taxon. Ideally, surveys should be undertaken to provide field data on population status across the range of each taxon, in both fire-affected areas and locations not affected by the 2019–20 fires.

Mammals - spatial overlaps of fire with distributions

Of the 56 taxa (46 species) in this analysis, the proportion of a taxon's distribution that was burnt ranged up to a maximum of 95%, for the Kangaroo Island Dunnart. This taxon also had the largest value for the proportion of its distribution burnt in a severe fire (90%). Another Kangaroo Island endemic, the Kangaroo Island Echidna, was the fourth ranked taxon in terms of fire overlap with its distribution, with a 63% overlap, but the second-ranked in terms of its overlap with severe fire (53%). On the mainland, the taxon with the largest distributional overlap with fire was the Long-footed Potoroo at 80% overlap, with 38% being burnt in severe fire (Figs. 12, 13; Appendix 1b).

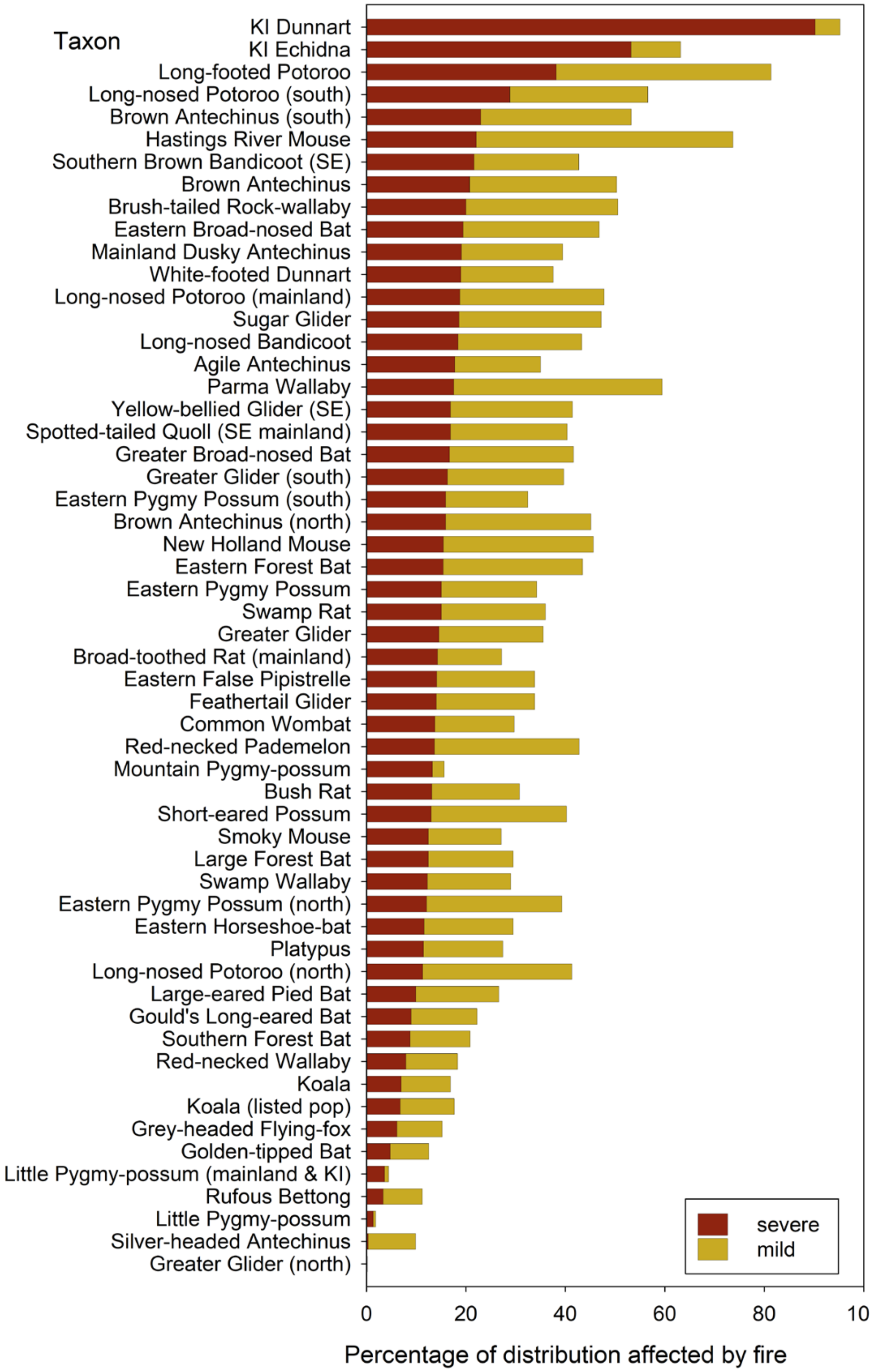


Fig. 12. The distributional overlaps with severe and mild fire for 56 mammal taxa. Species and constituent subspecies are displayed separately.

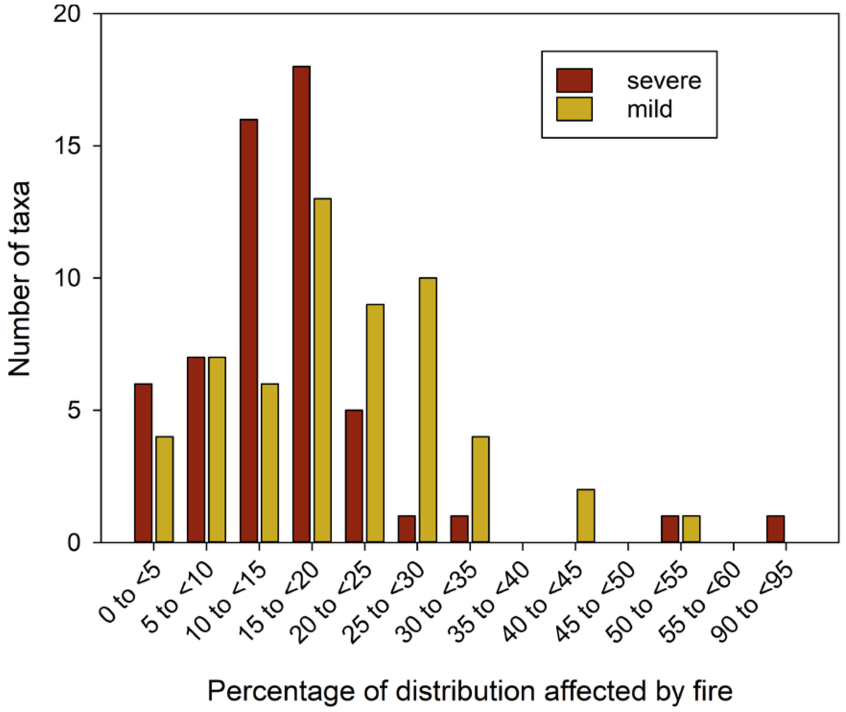


Fig. 13. The distribution of fire overlap proportions across 56 mammal taxa, displayed for severe and mild fire separately.

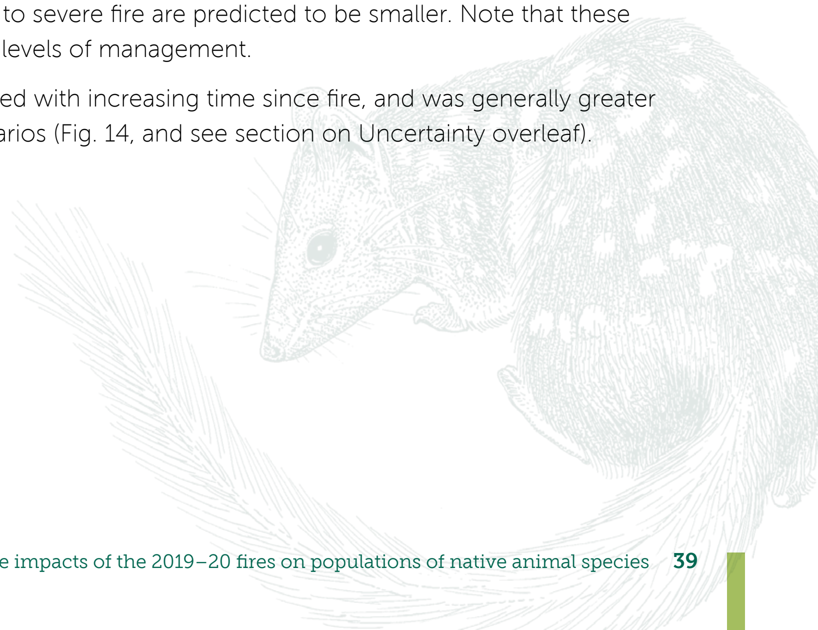
Mammals – expert estimates of local population response to fires of varying severity

Of the 56 mammal taxa (46 species) included in the spatial analyses, expert elicitation on the local population response to fires of different severity was carried out for 43 taxa from 34 species; these were taxa for which initial assessment indicated higher fire overlap values, or a poor conservation status, such as Silver-headed Antechinus *Antechinus argentus*.

The expert judgements on local population changes for each taxon, in the event of no fire, mild fire and severe fire, at one week, at one year post-fire, and at 10 years/three generations post-fire, are summarised in Fig. 14. Taxa whose populations were considered to be most heavily impacted by severe fire are nearer the bottom of the left-hand panel, and include the Greater Glider (both subspecies), Yellow-bellied Glider, Mainland Dusky Antechinus, and Koala, all of which were considered to have experienced immediate local population losses of over 75%, with the 80% confidence bounds approaching 100%. In contrast, populations of taxa near the top of the graph, such as the Eastern Horseshoe Bat, and the Platypus, are considered to be less immediately impacted by severe fire at a site.

The second panel, which summarises the population changes at a site one year after fire, shows that the ordering of taxa in terms of relative fire impacts, is mostly similar to the first panel (i.e., immediately after fire). However, the size of population loss generally increased, reflecting expert opinion that mortality rates in the year after fire are elevated for many taxa. By 10 years/three generations, taxa were re-ordered more substantially, depending on the expert judgement about the recovery trajectories. The relative difference in size between populations exposed to mild fire and no fire are much reduced, the populations exposed to severe fire are predicted to be smaller. Note that these projected estimates assume the continuation of current levels of management.

Uncertainty about the local population response increased with increasing time since fire, and was generally greater for the severe fire scenario than the mild or no fire scenarios (Fig. 14, and see section on Uncertainty overleaf).



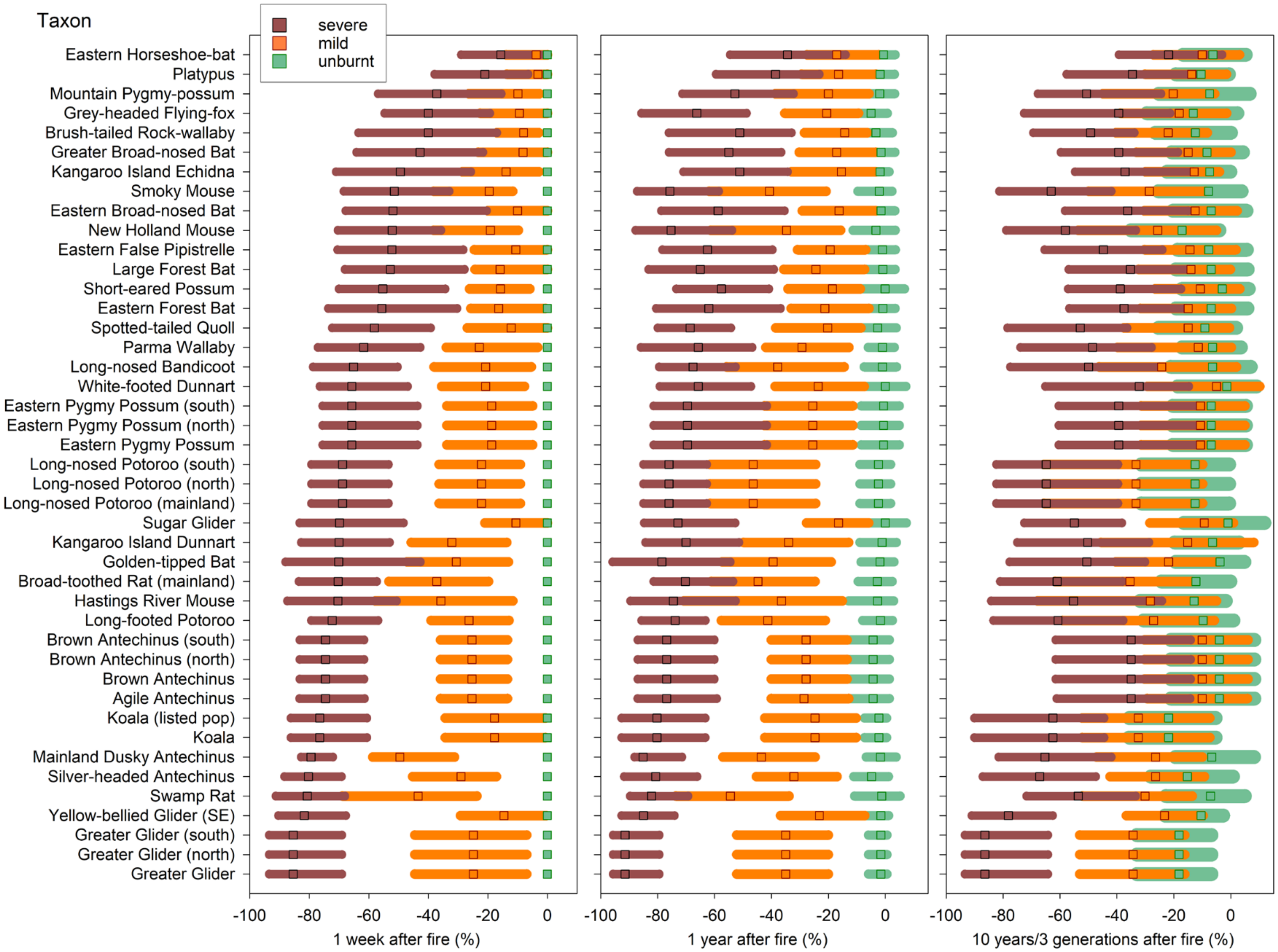


Fig. 14. The expert judgements on the population changes at a site, from just before the fire, to 1 week, 1 year, then 10 years/three generations (whichever is longer) after severe fire, mild fire, and no fire at the site. Each bar shows the plausible estimate and the 80% confidence bounds, averaged across experts.

Mammals – estimated overall proportional population decline for each species

The expert estimates for proportional population change after fires of varying severity, assuming conditions of current management, were combined with the estimates for the proportions of each taxon's distribution affected by each fire class to derive estimates of the overall population change in each taxon. The effects of management, including enhanced management, on population change are explored in a companion report.

The estimates for the overall proportional population change in these taxa, at three time points after fire, are shown in Fig. 15. In these estimates for population change, the proportions of mammals in burnt patches that escaped the fire by fleeing the hypothetical habitat patch have been added to the proportions that survive the fire and remain in situ. By one year, some of these escapees will have died (e.g. from lack of alternative habitat), some may have returned to the habitat patch, and some may still survive off-patch; the estimates presented here omit the unknown proportion of the population still surviving off-patch at one year, but we note this is likely to make a small difference to overall population estimates. By ten years, we assume escapees are likely either dead or have returned to their original habitat patch.

The estimates for overall population decline immediately after the fire average to a 16% reduction across all 43 taxa in the expert elicitation; and range from close to zero for the northern subspecies of the Greater Glider, whose distribution was minimally affected by fire, to 65% for the Kangaroo Island Dunnart, whose distribution overlapped with fire by 95%. By one year after fire, the population changes across all elicited taxa averaged a 20% reduction (with a maximum of 65%, again for the Kangaroo Island Dunnart), reflecting that in most species, the post-fire conditions cause additional mortality. By ten years/three generations, the average overall decline relative to pre-fire population size was 19%, indicating that experts predict little population recovery, on average. Inspection of the 80% confidence bounds suggest that three species may be reduced by 50% one year post fire, and that five species may be reduced by at least 50% by 10 years/three generations post fire. In general, the confidence bounds of estimated population changes for each taxon increased with time after fire (Fig. 15).

The bounds of the population size loss at 10 years/three generations overlap with zero (meaning population recovery to 2019–20 levels is plausible) for only 16 taxa, and the average estimates for all species remain below zero.

In 25 taxa, the mean estimate for the overall population size is similar or decreases between one year, and 10 years/three generations post-fire, indicating poor recovery or continuing decline (Fig. 16). Ongoing declines from just after fire through to one year and then 10 years/three generations after fire are marked for several species, including the Greater Glider (both subspecies), Koala, and Yellow-bellied Glider. Variation in post-fire recovery among species could reflect the time required for critical resources to re-establish, difference in management inputs and their effectiveness, or that the taxon is experiencing ongoing decline due to other threats, in some cases with these other threats compounding fire effects.

To disentangle any legacy effects of fire on the longer-term population trajectory, we compared the estimates for the overall population change after fire to the estimates for population change in the unburnt scenario, for each taxon (Fig. 16). The differences between the predicted population changes at 10 years/three generations, with and without the 2019–20 fires, are summarised again in Fig. 17. The taxa with the largest population deficit (by up to 40%) as a result of the 2019–20 fires are the Kangaroo Island Dunnart, the two species of potoroo and the Hastings River Mouse; the fire extent overlapped with large proportions of the distributions of these species.

Note that the expert judgements on the population change after fire included an assumption of no further large-scale fires. However, projections of future climate and fire risk suggests that this is unrealistic (Williams *et al.* 2009; Di Virgilio *et al.* 2019). The population curves shown in Fig. 16 are therefore likely to be underestimates, especially for longer-lived species.

If fire class 2 was grouped with unburnt, rather than with mild fire, the average population decline was reduced by 1.6%, 2.1% and 0.8% one week, one year, and 10 years/three generations after fire respectively. Only three taxa (two species) had estimates for population declines with differences that exceeded 5% in any time period, depending on how fire class 2 was categorised: the Hastings River Mouse at one week then one year post fire declined by an additional 7% when fire class 2 was categorised as a mild fire rather than unburnt; by 10 years, the difference between the estimates was reduced to 3%. The Long-footed Potoroo and the northern subspecies of the Long-nosed Potoroo had population decline estimates at one year that differed by 5%, depending on how fire class 2 was categorised (by 10 years the difference had reduced to 2%). We note that all three species were amongst the most heavily impacted of mammal taxa, and the categorisation of fire class 2 does not have a material effect on the predictions for the longer-term trajectories.

Platypus

The Platypus is the only mammal species in our assessment that is aquatic, and some post-fire sedimentation impacts could affect this species, especially those that are of longer duration, transform the riverbed shape or substrate, or remove food resources for an extended period. However, some post-fire events, such as a short term drop in dissolved oxygen, will not adversely affect Platypus even though it could kill fish. We explored the implications of using the aquatic impacts model instead of the fire severity map on the population trajectory estimates for the Platypus.

The proportion of the Platypus' distribution impacted by fire varied slightly depending on whether we intersected its range with the fire severity map or the aquatic impact spatial model.

- The Platypus range overlaps with the fire severity mapping by 27.3%, and 11.5% of its range overlapped with severe fire. This estimate classes fire class 2 as mildly burnt.
- When using the aquatic impacts model, 23% of the Platypus' range overlapped with aquatic impacts, and 19.7% overlapped with severe impacts.

Following these variations through to estimates of population decline:

- Fire severity map: suggests the Platypus experiences population declines of 2.9%. 8.4%, 13.7% at one week, one year, and 10 years/three generations after fire
- Aquatic impacts model: suggests the Platypus experiences population declines of 4.3%. 9.6%, 15.3% at one week, one year, and 10 years/three generations after fire.

These estimates are very similar; we use the fire severity map overlaps in the following graphs.

*KI Dunnart (*Sminthopsis fuliginosus aitkeni*). Image: Jody Gates*

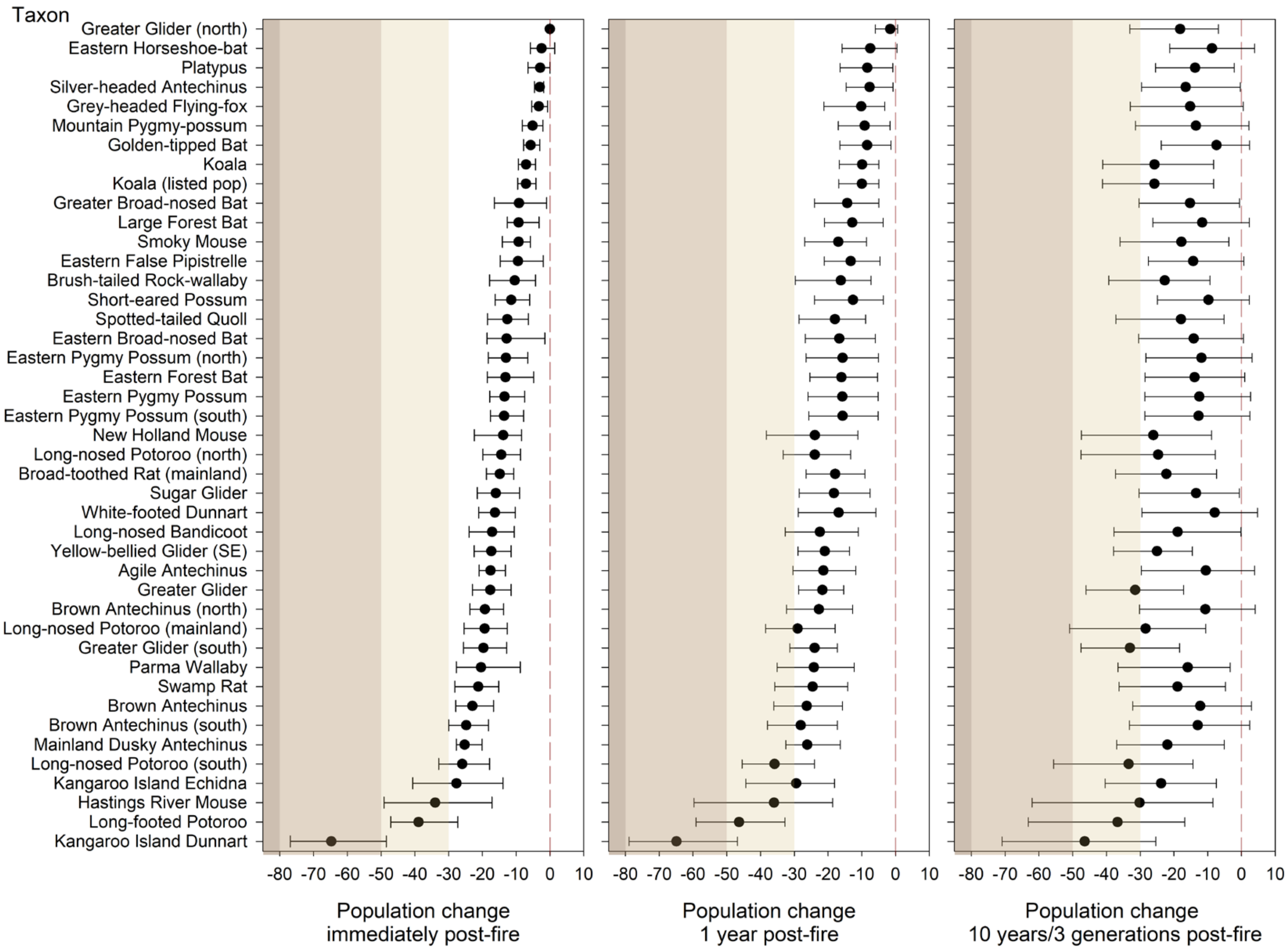
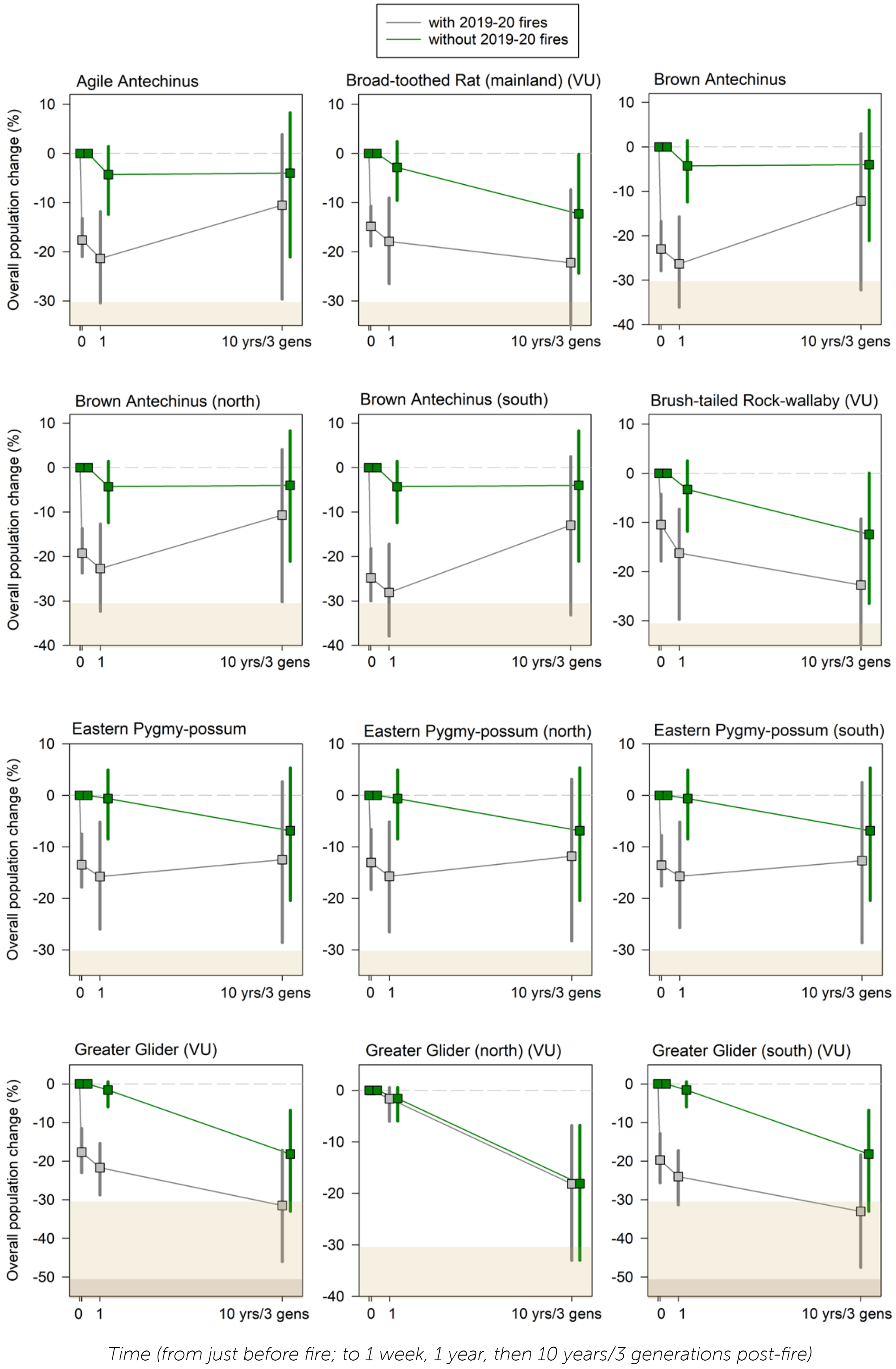
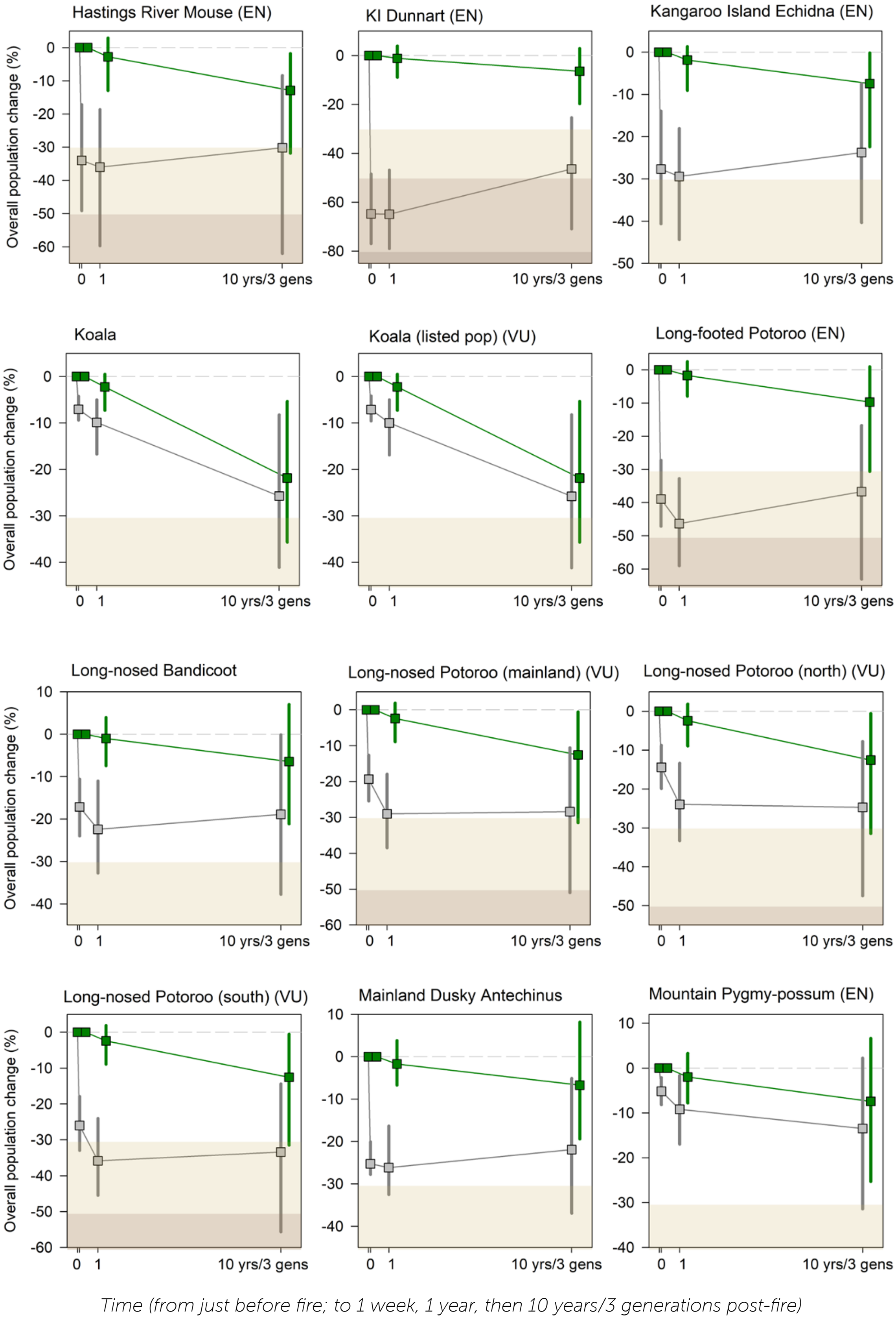
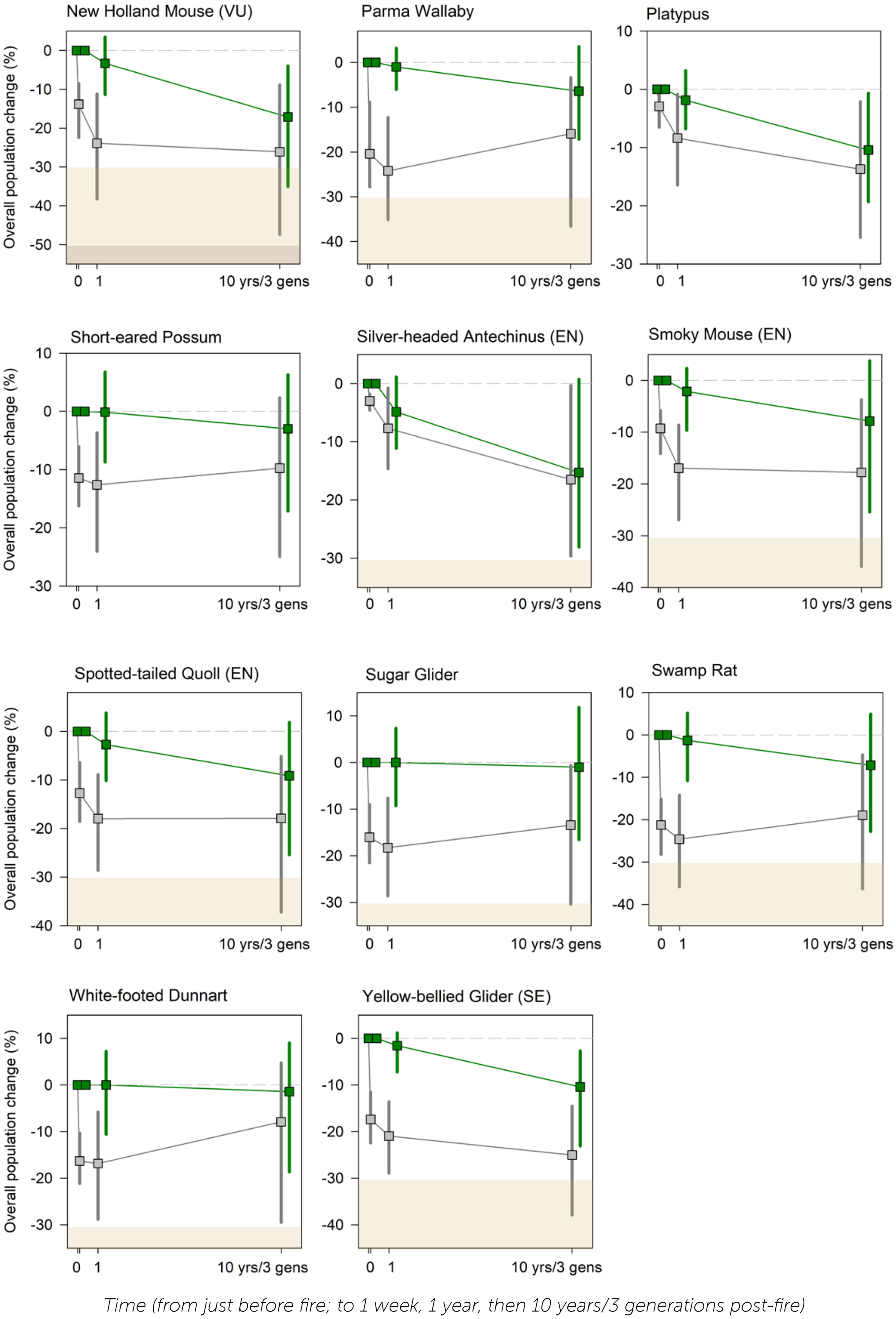


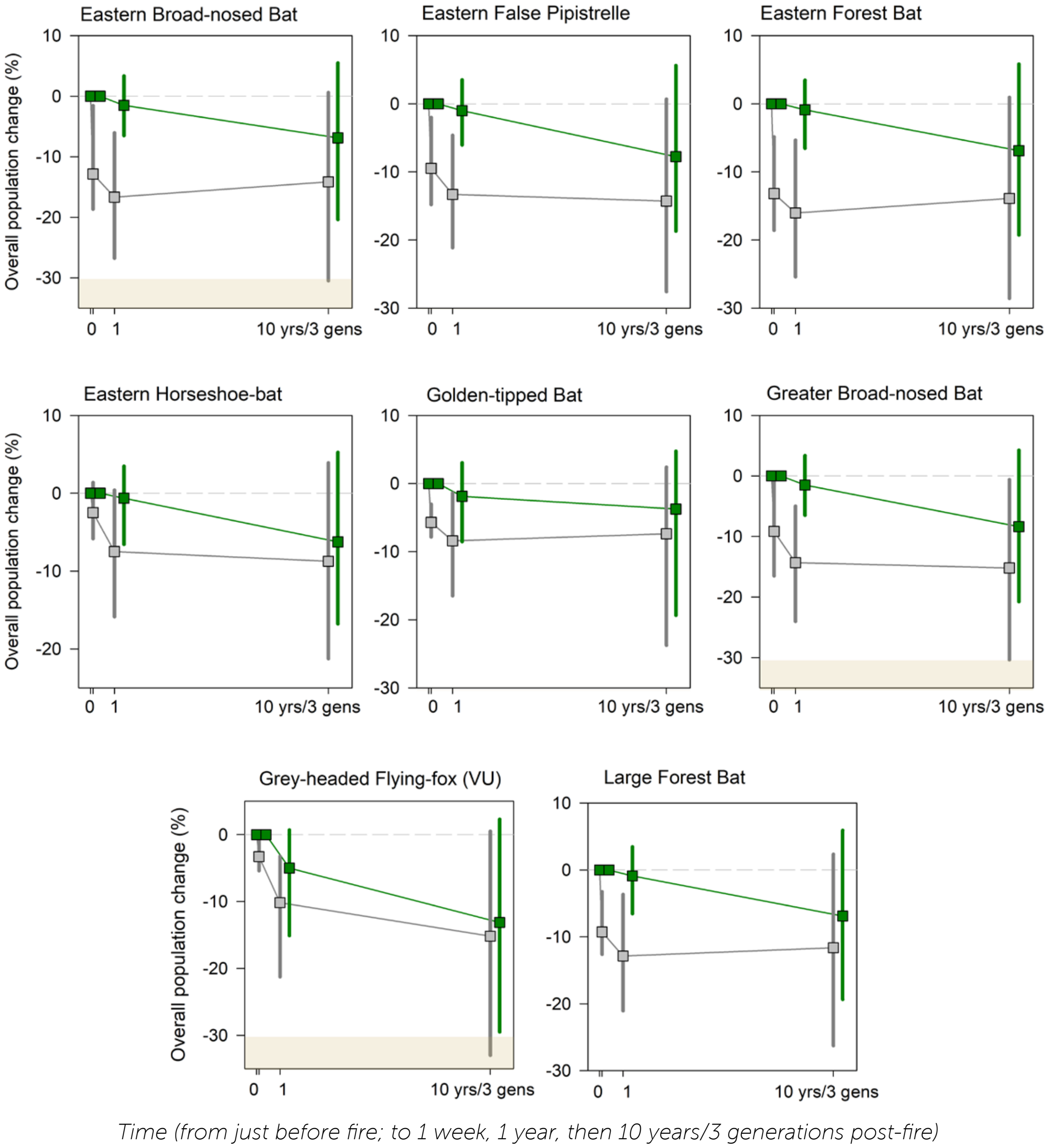
Fig. 15. The overall population change in 43 mammal taxa (those for which we included elicitations), 1 week, 1 year and 10 years/3 generations after the 2019–20 fires. Taxa are arranged in order of increasing population decline immediately after fire. The estimates are based on combining expert judgement on population response to fires of different severity, with spatial analysis of the proportion of each taxon's range affected by fires of each severity. The graphs show the average estimates and 80% confidence bounds across the expert judgements, and assume current management conditions. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%; dark brown is 80%).

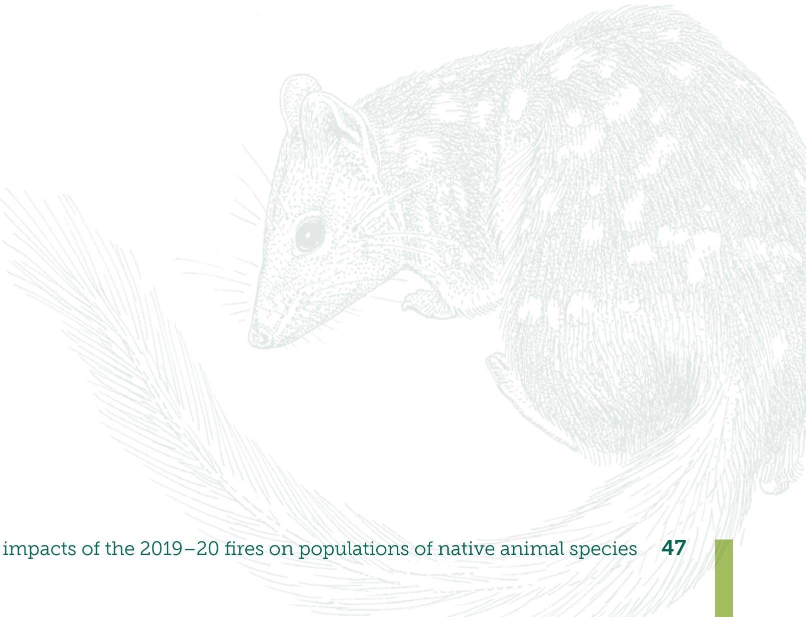
Fig. 16. (next 4 pages) *Changes in overall population size for each of the 43 taxa subject to elicitation, given the 2019–20 fires (grey lines), and if the fires had not occurred (green lines). Population changes are based on the expert judgements of how each taxon responds to fires of varying severity, combined with the spatial analyses of the proportions of each taxon's range that overlapped with fires of varying severity. Errors represent the average 80% confidence bounds across experts. Both population responses assume no further large-scale fire within the 10 year/3 generation period. Taxa are arranged alphabetically by common name, with bats grouped separately at the end. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%; dark brown is 80%).*




Hastings River Mouse (EN)
KI Dunnart (EN)
Kangaroo Island Echidna (EN)
Koala
Koala (listed pop) (VU)
Long-footed Potoroo (EN)
Long-nosed Bandicoot
Long-nosed Potoroo (mainland) (VU)
Long-nosed Potoroo (north) (VU)
Long-nosed Potoroo (south) (VU)
Mainland Dusky Antechinus
Mountain Pygmy-possum (EN)
Overall population change (%)
10
0
-10
-20
-30
-40
-50
-60
-80
0
1
10 yrs/3 gens
Time (from just before fire; to 1 week, 1 year, then 10 years/3 generations post-fire)


New Holland Mouse (VU)
Parma Wallaby
Platypus
Short-eared Possum
Silver-headed Antechinus (EN)
Smoky Mouse (EN)
Spotted-tailed Quoll (EN)
Sugar Glider
Swamp Rat
White-footed Dunnart
Yellow-bellied Glider (SE)
Overall population change (%)
10
0
-10
-20
-30
-40
-50
0
1
10 yrs/3 gens
Time (from just before fire; to 1 week, 1 year, then 10 years/3 generations post-fire)


Eastern Broad-nosed Bat
Eastern False Pipistrelle
Eastern Forest Bat
Eastern Horseshoe-bat
Golden-tipped Bat
Greater Broad-nosed Bat
Grey-headed Flying-fox (VU)
Large Forest Bat
Overall population change (%)
10
0
-10
-20
-30
0
1
10 yrs/3 gens
Time (from just before fire; to 1 week, 1 year, then 10 years/3 generations post-fire)



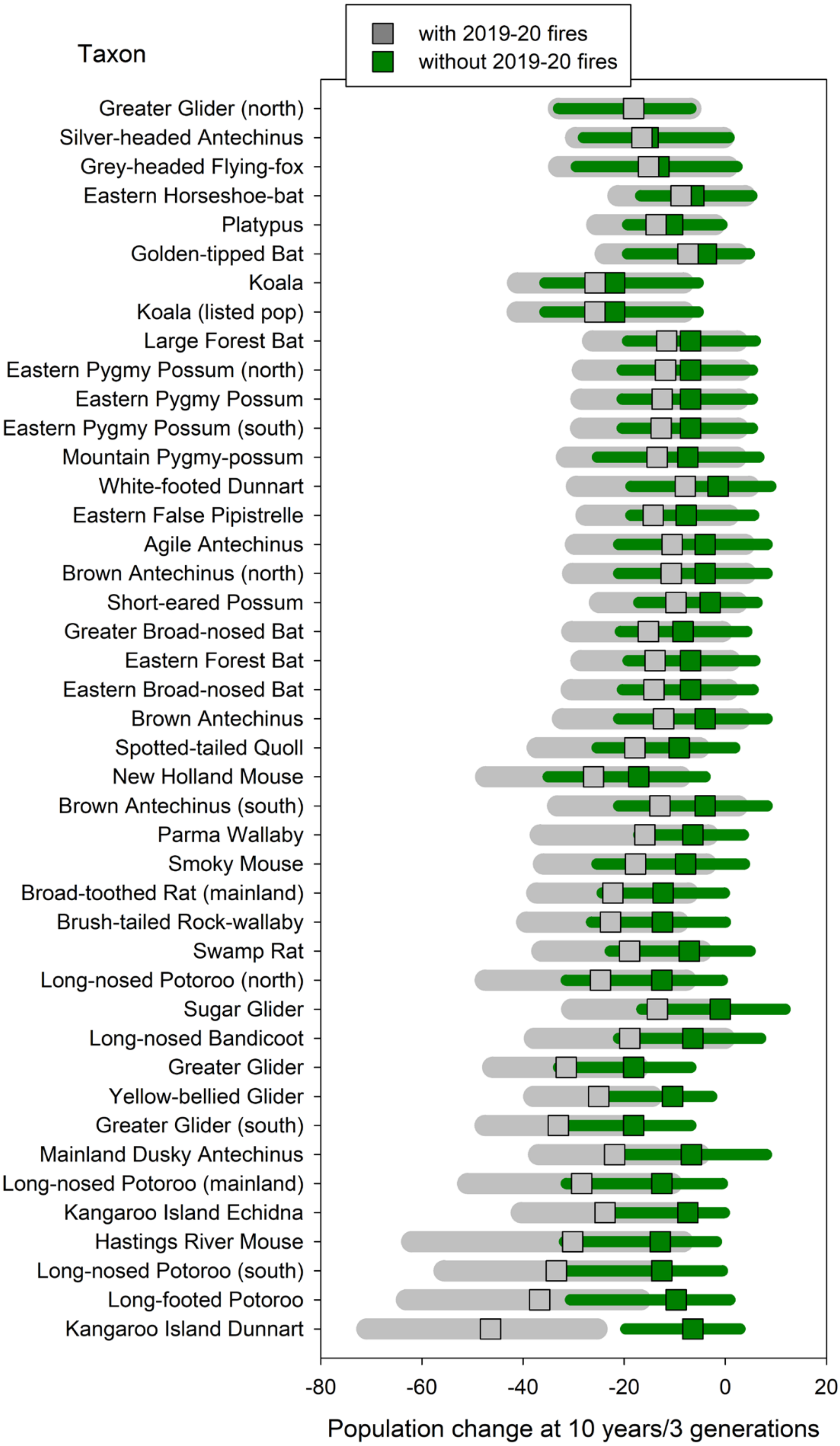


Fig. 17. The legacy effects of the 2019–20 fires, 10 years/three generations later. The graph shows the predicted population change, with 80% confidence bounds, for each taxon given the 2019–20 fires (grey), and if the fires had not occurred (green). Species are sorted on this graph by the magnitude of the legacy effects of fire: these are greater in taxa near the bottom of the graph, where the differences in predictions for overall population change between burnt and unburnt scenarios are largest.

Mammals – priorities for conservation status review

The 56 mammal taxa (from 46 species) considered in this assessment have experienced overall population declines of varying magnitude as a result of the 2019–20 fires; we estimated the population loss using expert elicitation for 43 of these taxa (34 species). The elicitation showed that taxa may partially recover over 10 years/three generations, but they will still have diminished populations relative to the size they could have been, had the fires not occurred (Figs. 16, 17). In addition, these predictions assume no further extensive fire events, but climate modelling identifies that periods of extreme fire weather will become increasingly common (Williams *et al.* 2009; Di Virgilio *et al.* 2019). Thus, the predictions are likely to be underestimates, especially for long-lived taxa. Recurrent fires that occur before full recovery has occurred will gradually culminate in a downward population trajectory.

We reviewed the estimated population change immediately after fire, at one and 10 years/three generations for all taxa included in the expert elicitation, and their current conservation status under the EPBC Act, as well as in the Mammal Action Plan (Woinarski *et al.* 2014), and on the IUCN Red List. We focussed on the most plausible estimate and the lowest 80% confidence bound for the population loss, to develop the following guidelines:

- If the most plausible predicted estimate for population loss in any time period exceeds a relevant threshold that would cause the taxon to be listed or uplisted under Criterion A (30% if the taxon is currently unlisted; 50% if currently listed as VU; 80% if currently listed as EN), we recommend the taxon be assessed/re-assessed.
- If the predicted population decline approaches a relevant threshold (i.e. the plausible bounds include the threshold but the most plausible estimate does not exceed it), then:
    - If the taxon is listed (or listed in a higher category) by Woinarski *et al.* (2014) or by the IUCN Red List, but not by the EPBC Act, then this suggests there is evidence of decline additional to the substantial impacts of the 2019–20 fires, and the taxon should be assessed/re-assessed.
    - If the taxon is not listed, or not listed at a higher category, by Woinarski *et al.* (2014) or by the IUCN Red List, assessment or re-assessment could still be warranted. For example, if the taxon has a restricted distribution or population size, and has experienced declines as a result of the fire which may continue (given increasing fire frequencies), then the taxon could be eligible for listing under Criteria B or C. This was reviewed case by case.

We also reviewed the potential for conservation status changes in taxa where we carried out spatial analysis of fire impacts, but did not elicit information on population response to fire. Of these 13 taxa, two are currently listed as nationally threatened. The Southern Brown Bandicoot *Isoodon obsesulus obesulus* is currently listed as Endangered under Criterion A for having experienced population declines exceeding 50%; 43% of its distribution overlapped with the 2019–20 fires, and 22% with severe fire. The Large-eared Pied Bat *Chalinolobus dwyeri* is listed as Vulnerable on the basis of population declines; 27% of its distribution overlapped with fire, and 10% with severe fire. We recommend that listing re-assessment should be considered for both taxa.

To assess whether listing assessment was warranted for the remaining 11 taxa, we first examined the relationship between predicted population declines and the fire distributional overlap in taxa for which we had elicited information on population fire response. The population change at one year had a close relationship to the proportion of a taxon's distribution that overlapped with the fire extent, particularly with the extent of severe fire (Fig. 18). Based on this information, we developed this guideline for the 11 unlisted taxa for which we only had fire overlap information:

- If the proportion of a taxon's distribution that was burnt is greater than 35%, and the proportion burnt in a severe fire is greater than 15%, the overall population loss may exceed 30% and we recommend the taxon be assessed.

Using these guidelines to review the conservation assessment priorities across 56 mammal taxa, we have identified that the 2019–20 fires have had impacts sufficient to cause 1-5 previously unlisted taxa to potentially be eligible for listing as nationally threatened, and to cause 9-13 taxa already recognised as nationally threatened to be eligible for uplisting (Fig. 19). Thirty taxa are unlikely to qualify for listing, and eight threatened taxa are unlikely to qualify for uplisting (Fig. 19). For a full conservation assessment, our estimates for population declines and fire impacts will need to be considered in the context of other information on declines, and other information on past and future predicted population trajectories.

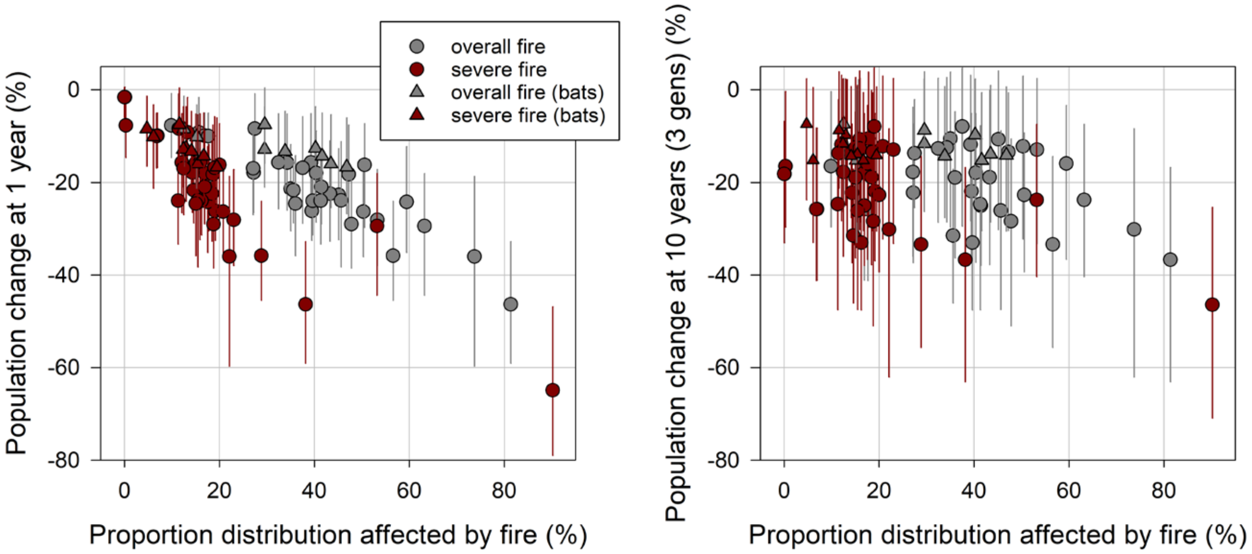


Fig. 18. The population change, as estimated by experts, for 43 taxa at 1 year (left), and at 10 years (right) against the proportions of their distributions that overlapped with the fire extent (grey) and with severe fires (brown). Bats are displayed with a different symbol.

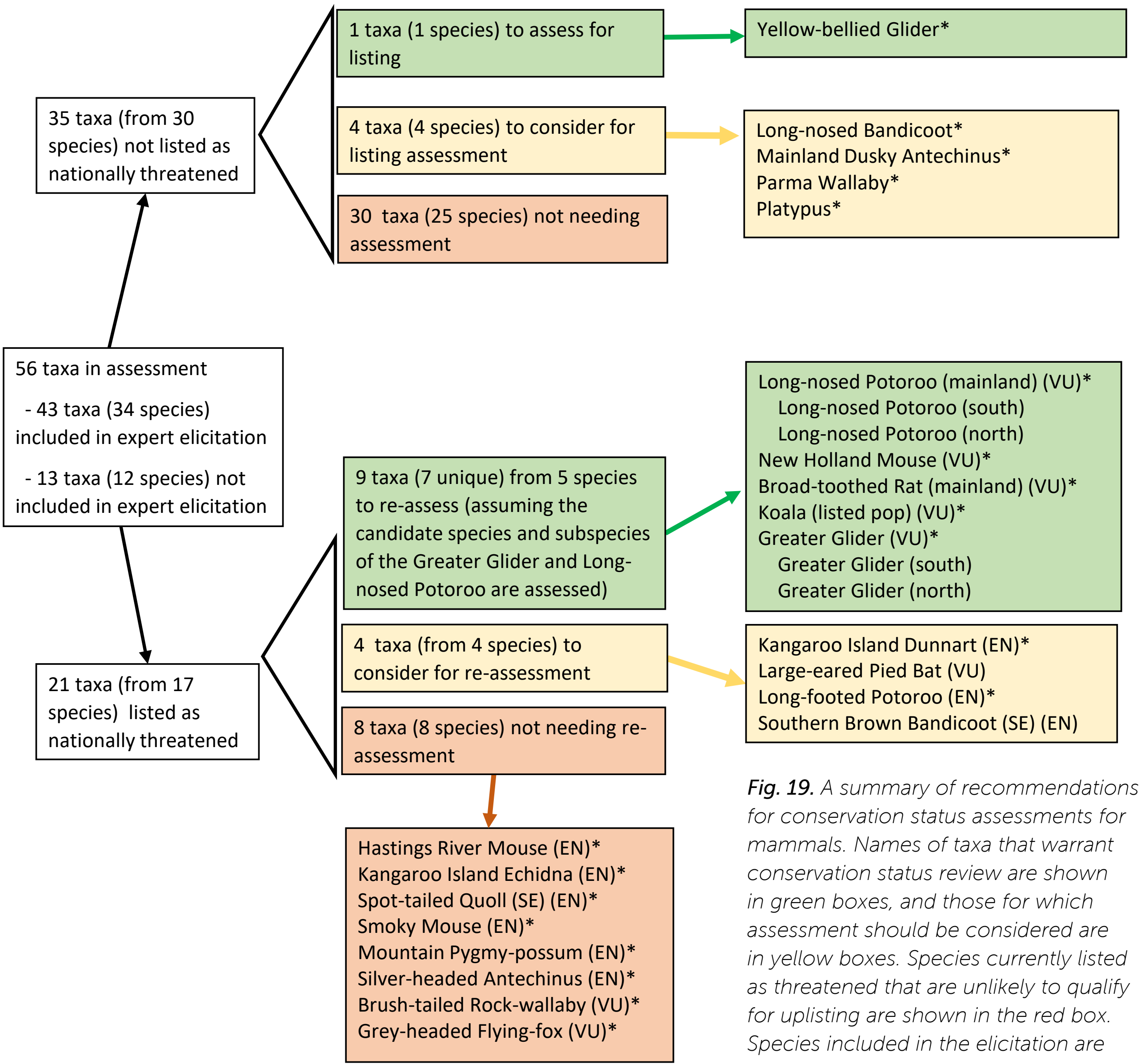


Fig. 19. A summary of recommendations for conservation status assessments for mammals. Names of taxa that warrant conservation status review are shown in green boxes, and those for which assessment should be considered are in yellow boxes. Species currently listed as threatened that are unlikely to qualify for uplisting are shown in the red box. Species included in the elicitation are marked with an asterisk. The full list of taxa with more detail on the reasoning for the recommendations is in Appendix 1b.

Frogs - summary

- 66 taxa (47 species) were included in the spatial analysis based on preliminary screening that indicated that fire may have overlapped with their distribution by > 10% if listed, and > 25% if not listed.
    - The taxon with the largest fire overlap (91%) was *Philoria pughi*.
    - The taxon with the greatest distributional overlap with severe fire was the recently described *Litoria watsoni* (44%).
    - Three taxa did not have distributions that overlapped with fires: *Limnodynastes dumerilii insularis*, *Taudactylus pleione*, *Uperoleia mahonyi*.
- We carried out expert elicitation to estimate the local population response to no, mild and severe fires for 31 taxa from 22 species.
    - The taxa with the most extreme local population decline when exposed to severe fire were assessed to be the two highly threatened species of Corroboree Frogs *Pseudophryne corroboree* and *Pseudophryne pengilleyi*, three species of *Litoria* (*L. subglandulosa. L. watsoni, L. littlejohni*) and all four *Philoria* species (*P. shagnicola, P. kundagungan, P. richmondensis, P. pughi*).
    - Conversely, taxa that experience the smallest local population declines when exposed to severe fire were considered to be burrowing frogs including *Heleioporus australiacus*, and three species of non-alpine *Pseudophryne* (*P. australis, P. dendyi, P. bibroni*).
    - Uncertainty about the local population response increased with increasing time since fire, and was greater for the severe fire scenario than the mild or no fire scenarios.
- We combined the estimates for the proportions of each taxon's distribution affected by each fire class with the expert estimates for proportional local population change when exposed to fires of varying severity (assuming conditions of current management) to derive estimates of the overall population change in each taxon.
    - The taxon with the largest mean estimate for population decline after fire was *Litoria watsoni* at 36% reduction one week post-fire, worsening to a 41% reduction by one year after fire, through a combination of high fire overlap and high predicted sensitivity to fire impacts. By 10 years/three generations after fire *Litoria watsoni* was still the taxon with the largest predicted decline, at 43% less than pre-fire levels.
    - In all but one taxon (*Pseudophryne australis*), the extent of population decline increased between one week and one year after fire, reflecting expert opinion about continued high mortality in the post-fire environment.
    - In 23 taxa, the mean estimate for the overall population size is very similar or decreases between one year, and 10 years/three generations post-fire, indicating poor recovery or continuing decline (e.g. *Litoria spenceri, Philoria richmondensis*).
    - In 14 taxa, population size may recover to some extent, between one year and 10 years/three generations, in that the 80% confidence bounds around the population estimate at 10 years/three generations included zero (i.e. recovery to pre-fire population size is plausible). Four taxa have predicted population sizes close to zero (i.e. within 5%), but in no cases does the mean estimate for the population size at 10 years/three generation reach or exceed zero.
    - The long-term 'legacy' effects of the fire were predicted to be greatest for *Philoria pughi* and *Litoria watsoni*. In these taxa, the population size after three generations is predicted to be up to 30% less than it would have been, had the fires not occurred.
- The 63 frog taxa in our assessment with fire-affected distributions all experienced population declines as a result of the 2019–20 fires, but the extent of those declines, and the potential for population recovery, is variable. From reviewing the current conservation statuses in the EPBC Act, the IUCN Red List, and in Gillespie *et al.* (2020), and considering our estimates for population loss as a result of fire, we suggest that seven to 14 previously unlisted frog taxa may be eligible for listing as nationally threatened, and 11 to 12 taxa already recognised as nationally threatened may be eligible for uplisting.
- The status of another nine taxa (seven species) that are already listed under the EPBC Act has worsened, although this is not sufficient to warrant uplisting, or they are already listed as CR (n = 3 taxa).
- We stress that for a thorough conservation assessment, our estimates for population declines and fire impacts need to be considered in the context of other information on past and future population trajectories, and threat status, for each taxon. Ideally, surveys should be undertaken to provide field data on population status across the range of each taxon, in both fire-affected areas and locations not affected by the 2019–20 fires.

Frogs - spatial overlaps of fire with distributions

Of the 66 frog taxa (47 species) in the spatial analysis, the proportion of a taxon's distribution that was burnt ranged up to a maximum of 91%, for *Philoria pughi*. The taxon with the largest value for the proportion of its distribution burnt in a severe fire was the recently described *Litoria watsoni* (44%). (Figs. 20, 21; Appendix 1c). We note that several frog species have very small distributions (e.g. *Philoria kundagungan*, Bolitho *et al.* 2021), and our spatial analysis could underestimate the true fire extent overlap and thus the fire impacts for these species.

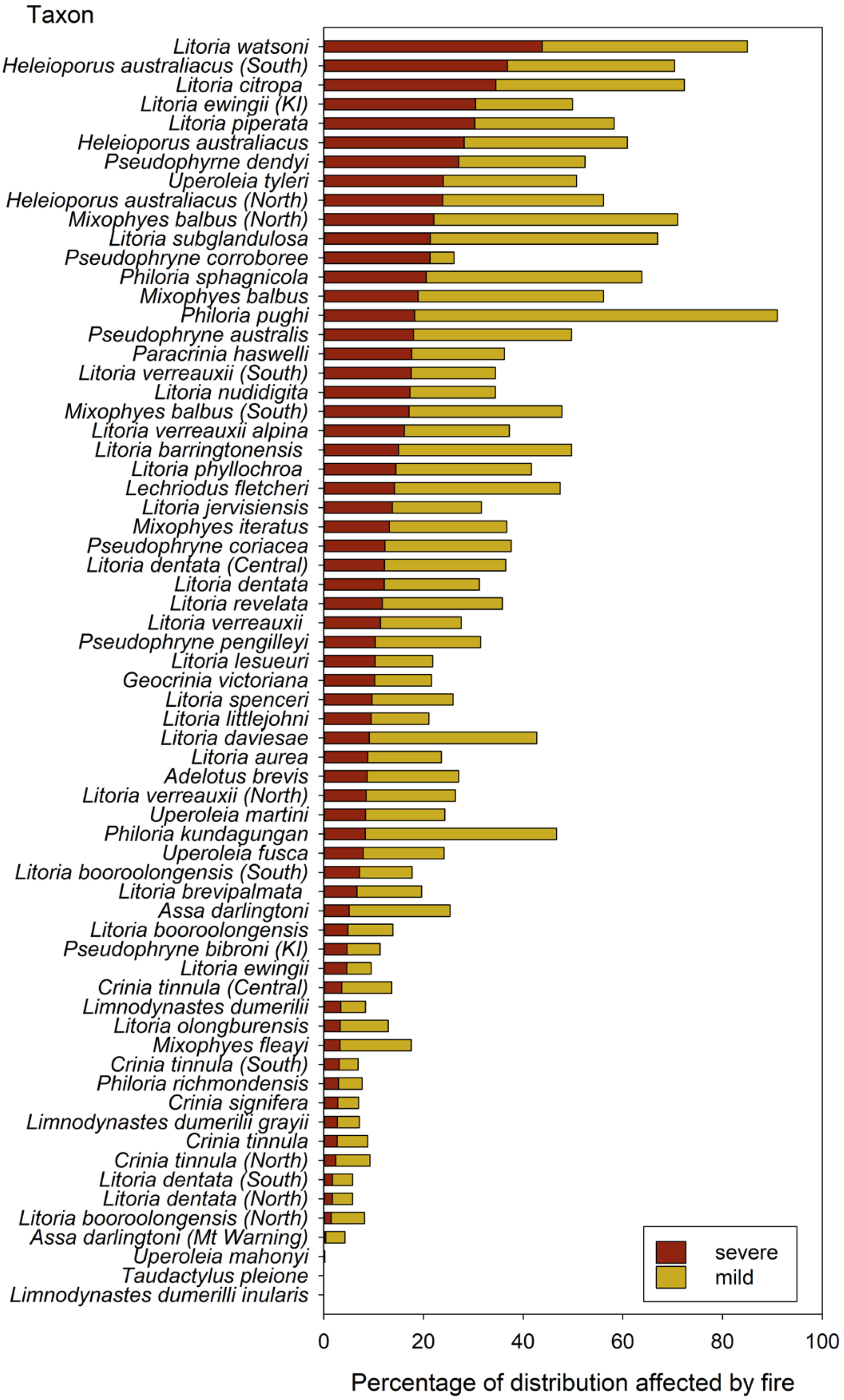


Fig. 20. The distributional overlaps with severe and mild fire for 66 frog taxa. Species and constituent subspecies are displayed separately.

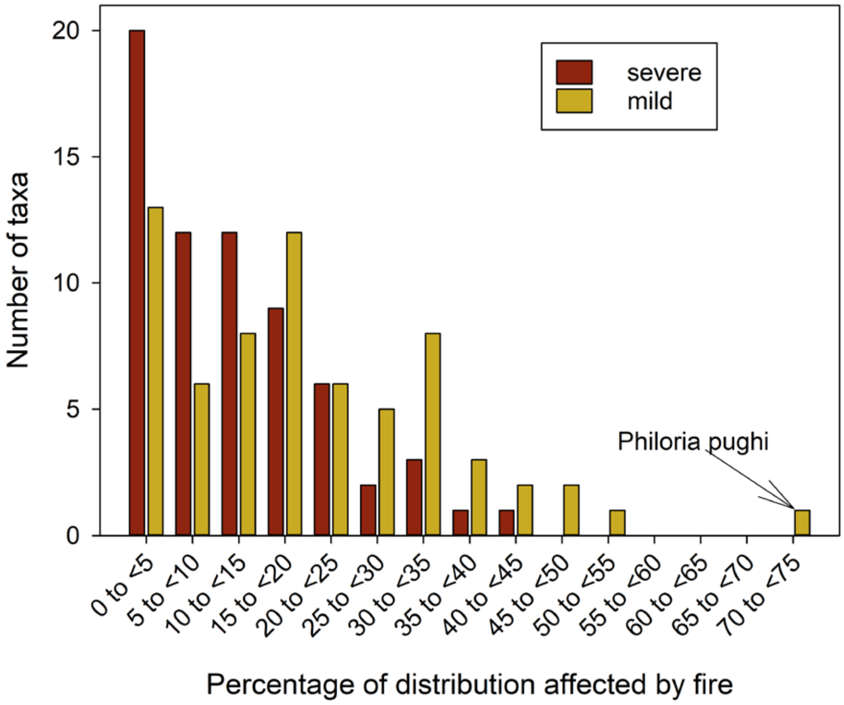


Fig. 21. The distribution of fire overlap proportions across 66 frog taxa, displayed for severe and mild fire separately.

Frogs – expert estimates of local population response to fires of varying severity

Of the 66 frog taxa (47 species) included in the spatial analyses, expert elicitation on the population response to fires of different severity were carried out for 22 species (31 taxa); these were taxa for which initial assessment indicated higher fire overlap values, or species with lower fire overlap estimates but with a poor conservation status, such as *Mixophyes fleayi* (EN), or *Philoria richmondensis* (EN in IUCN Red List). *Pseudophryne dendyi* was added to the elicitation set late in the project, and the expert estimates for *Pseudophryne bibroni* were applied to this taxon, as they were considered likely to respond similarly to fire impacts at a site.

The expert judgements on taxon population changes at a site in the event of no fire, mild fire and severe fire, at one week, at one year, and 10 years/three generations post-fire, are summarised in Fig. 22. These estimates assume the continuation of current levels of management. Taxa whose populations are considered to be immediately heavily impacted at a site level by severe fire are nearer the bottom of the left-hand panel, and include the two highly threatened species of Corroboree Frogs *Pseudophryne corroboree* and *Pseudophryne pengilleyi*. *Philoria* species included in the elicitation also cluster near the bottom of the graph, indicating relatively high population loss at a site level as a direct result of fire, whereas other burrowing frogs including *Heleioporus australiacus*, and three species of *Pseudophryne* cluster near the top of the graph, reflecting expert opinion that these species are relatively protected from the immediate effects of fire at a site.

By one year after fire, the ordering of taxa in terms of the relative population loss has rearranged, and this 'disordering' is marked by 10 years/three generations after fire (the right panel), as the impacts of other threatening processes come into play and affect the population trajectories variously across taxa. In general, the lingering effects of severe fire on population size are relatively more evident at 10 years/three generations than the effect of mild fire at that time point.

Uncertainty about the local population response increased with increasing time since fire, and was greater for the severe fire scenario than the mild or no fire scenarios (Fig. 22, and see section on Uncertainty overleaf).

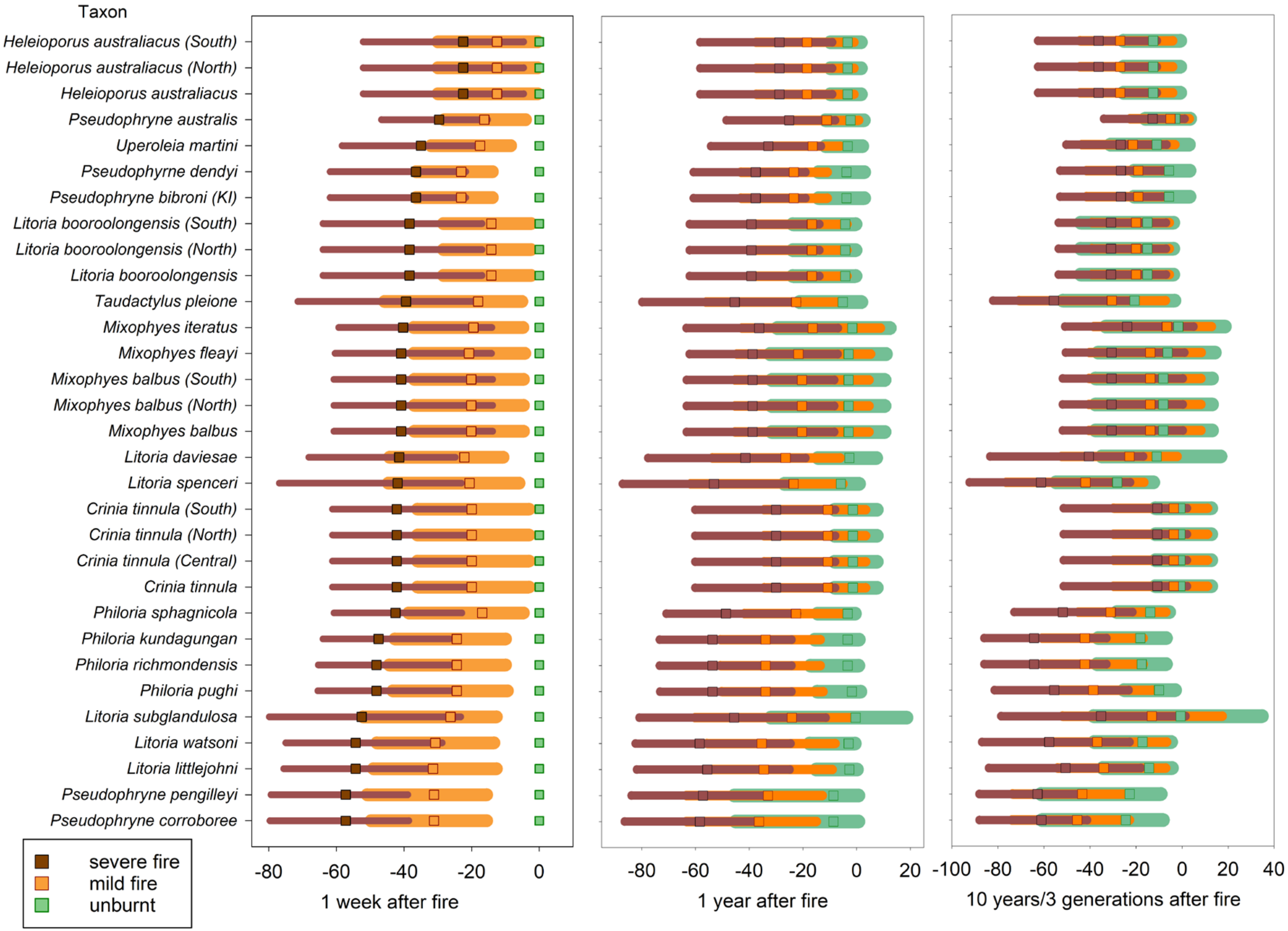


Fig. 22. *The expert judgements on the population changes at a site, from just before the fire, to 1 week, 1 year, then 10 years/three generations (whichever is longer) after severe fire, mild fire, and no fire at the site. Each bar shows the plausible estimate and the 80% confidence bounds, averaged across experts.*

Frogs – estimated overall proportional population decline for each species

The expert estimates for proportional population change after fires of varying severity, assuming conditions of current management, were combined with the estimates for the proportions of each taxon's distribution affected by each fire class to derive estimates of the overall population change in each taxon. The effects of management, including enhanced management, on population change are explored in a companion report.

The estimates for the overall proportional population change in these taxa, at three time points after fire, are shown in Fig. 23. The estimates for overall population decline immediately after the fire average to a 10% reduction across all 31 taxa in the expert elicitation. Decline estimates ranges from zero for *Taudactylus pleione* (because the spatial analysis indicated no overlap with the fire extent), to an immediate population loss of 36% for *Litoria watsoni*, which had a combination of high fire overlap plus expert predictions of high sensitivity to fire impacts.

By one year after fire, the population changes across all elicited taxa averaged a 13% reduction, indicating that experts considered the population status of frog species will continue to decline in the year after fire. This pattern of further population loss to one year was evident even in species that experienced little immediate population loss due to fire, indicating that other threats were impacting these species. In addition, species considered likely to recover over 10 years/three generations, such as *Crinia tinnula*, decline in the year after fire, suggesting that the post-fire environment is challenging for some species (Figs. 23, 24). *Litoria watsoni* was again the species with the largest predicted population loss at one year after fire, now at 41%. By 10 years/three generations after fire, the average population loss across all taxa was 18%, indicating ongoing declines for some taxa; *Litoria watsoni* was still the taxa with the largest predicted decline, at 43%. Inspection of the 80% confidence bounds suggest that five species may be reduced by 50% one year post fire, and that seven species may be reduced by at least 50% by 10 years/three generations post fire. In general, the confidence bounds of estimated population changes for each taxon increased with time after fire (Fig. 23).

The 80% confidence bounds of the population size loss for one third (10) of the taxa overlap with zero (suggesting population recovery to 2019–20 levels is plausible) by one year, and 14 taxa have bounds that overlap with zero so by 10 years/three generations, yet the average estimates for all species remain below zero (Fig. 23). By 10 years/three generations, *Crinia tinnula* populations are close to full recovery, with populations just 1% lower than their pre-fire size. Only nine taxa (five species) had populations at 10 years/three generations that were predicted to have increased relative to their population sizes immediately after fire: *Crinia tinnula* (all three candidate species), *Litoria subglandulosa*, *Mixophyes balbus* (northern taxon), *Mixophyes iteratus*, and *Pseudophryne dendyi*. Delays in post-fire recovery among species could reflect the time required for critical resources to re-establish, differences in management inputs and their effectiveness, or that the taxon is experiencing ongoing decline due to other threats, in some cases with these other threats interacting with fire impacts.

To disentangle any legacy effects of fire on the longer-term population trajectory, we compared the estimates for the overall population change after fire to the estimates for population change in the unburnt scenario, for each taxon (Fig. 24). The differences between the predicted population changes at 10 years/three generations, with and without the 2019-2010 fires, are summarised again in Fig. 25. The taxa with the largest population deficit (by 29%) as a result of the 2019–20 fires were *Philoria pughi* (29%), *Litoria watsoni* (26%), and the northern lineage of *Heleioporus australiacus* (14%).

The plots of population trajectories for individual species (Fig. 24) also show clearly that ongoing declines from just after fire through to one year and then 10 years/three generations after fire are very clear for several species, regardless of whether the populations were exposed to fire or not (e.g. *Heleioporus australiacus, Litoria booroolongensis*, all four species of *Philoria*).

Note that the expert judgements on the population change after fire included an assumption of no further large-scale fires. However, projections of future climate and fire risk suggests this is unrealistic (Williams *et al.* 2009; Di Virgilio *et al.* 2019). The population curves shown in Fig. 24 are therefore likely underestimates, especially for longer-lived species.

If fire class 2 was grouped with unburnt, rather than with mild fire, the average population decline was reduced by 1.9%, 1.9% and 1.3% at one week, one year, and 10 years/three generations after fire respectively. Only two taxa (two species) had estimates for population declines with differences that exceeded 5% in any time period, depending on how fire class 2 was categorised: *Litoria subglandulosa* had a decline 1 week after fire of 23% rather than 18% when fire class 2 was categorised as unburnt; the divergence reduced over time. *Philoria pughi* had declines that were greater by 10%, 13% and 11% at 1 week, 1 year then 10 years/three generations post-fire when fire class 2 was categorised as a mild fire. If fire class 2 was categorised as unburnt, the predictions for overall population loss would change to 17%, 22% and 28% by one week, one year, and 10 year/three generations. The ranking of the taxon relative to other taxa would change little: the species would move from being the second most impacted taxon immediately after fire to the third most impacted; it would remain the second most impacted taxon one year after fire; at 10 years/three generations, it would the fifth most impacted taxon rather than the second.

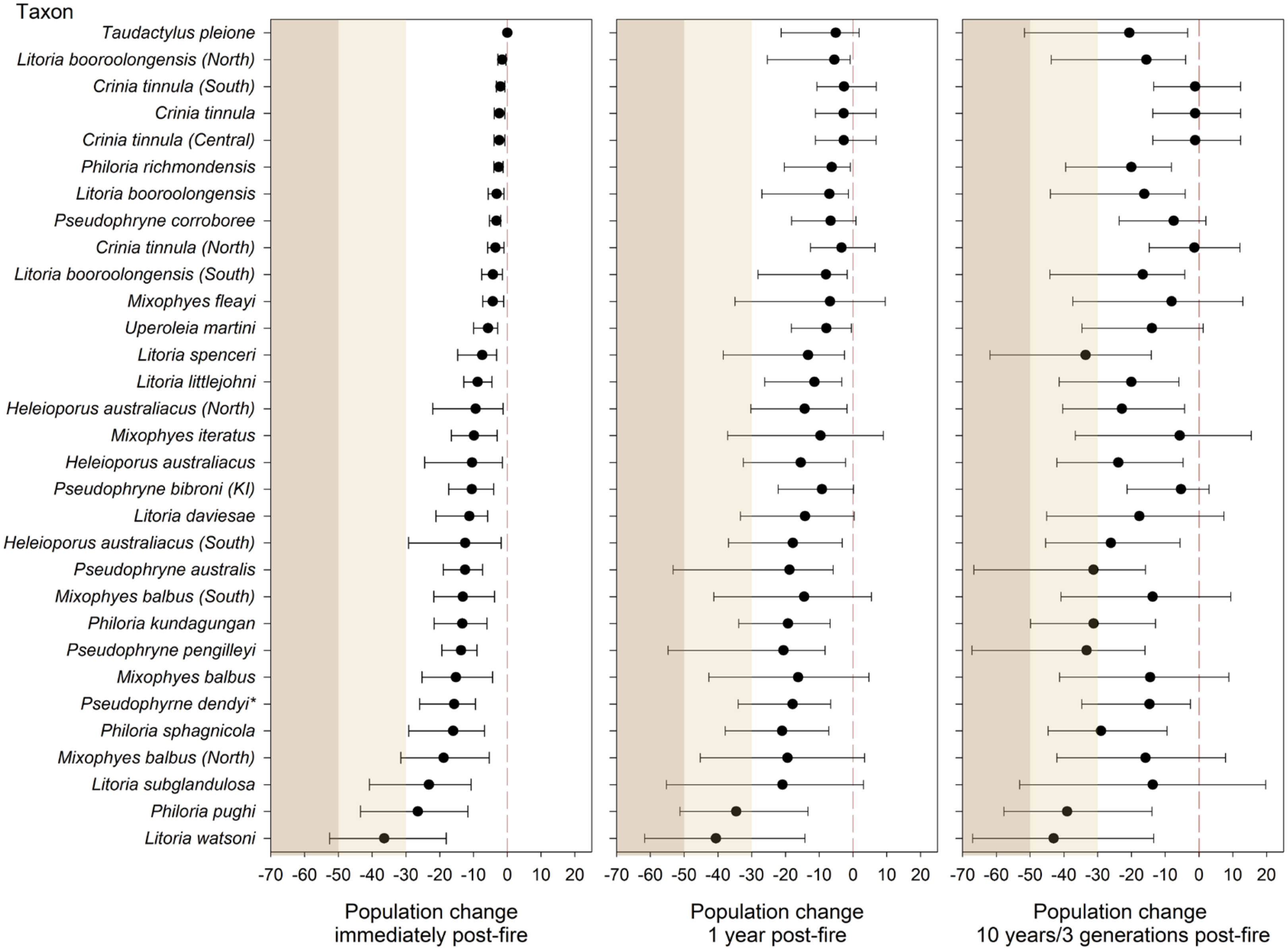
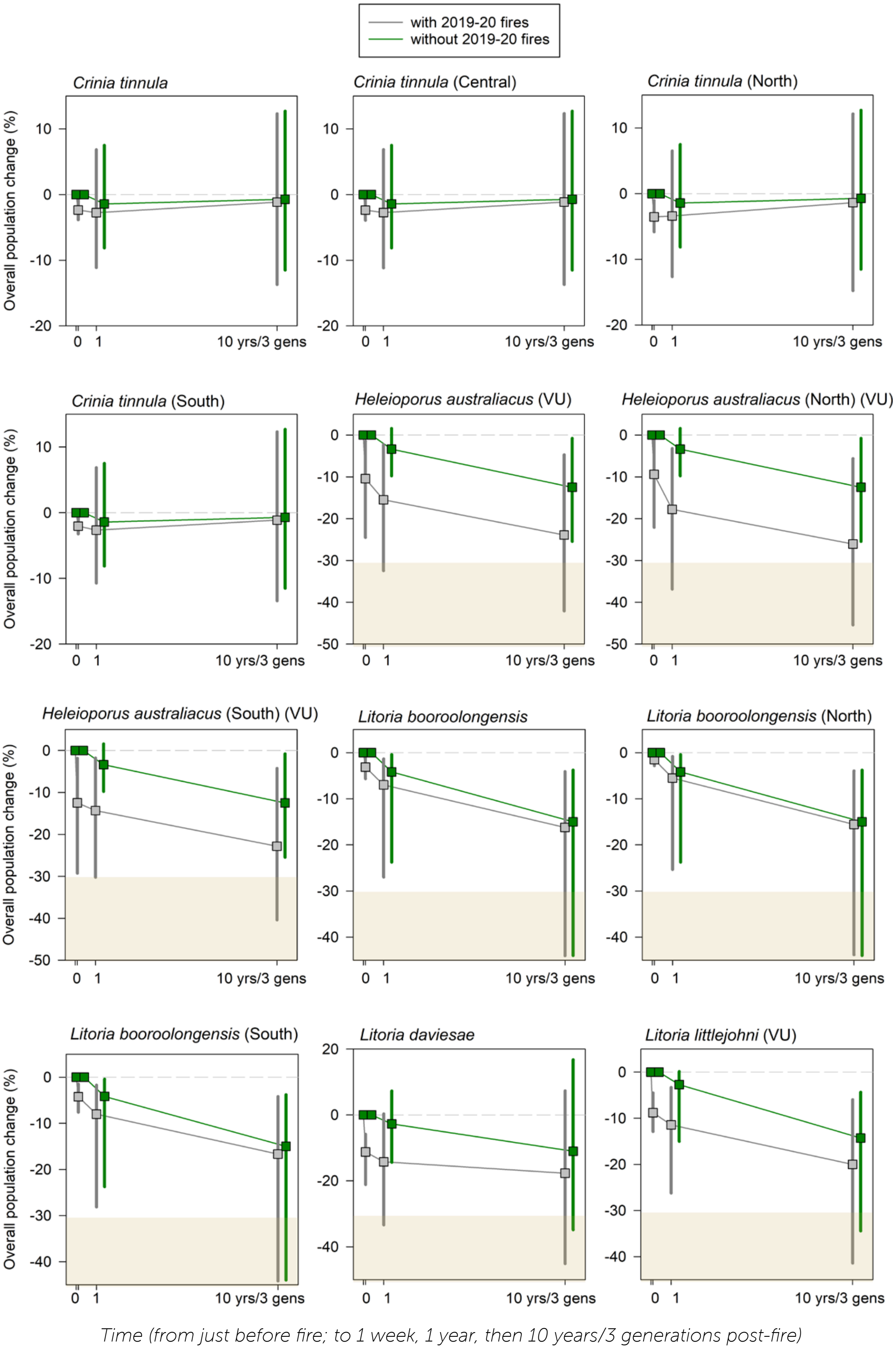
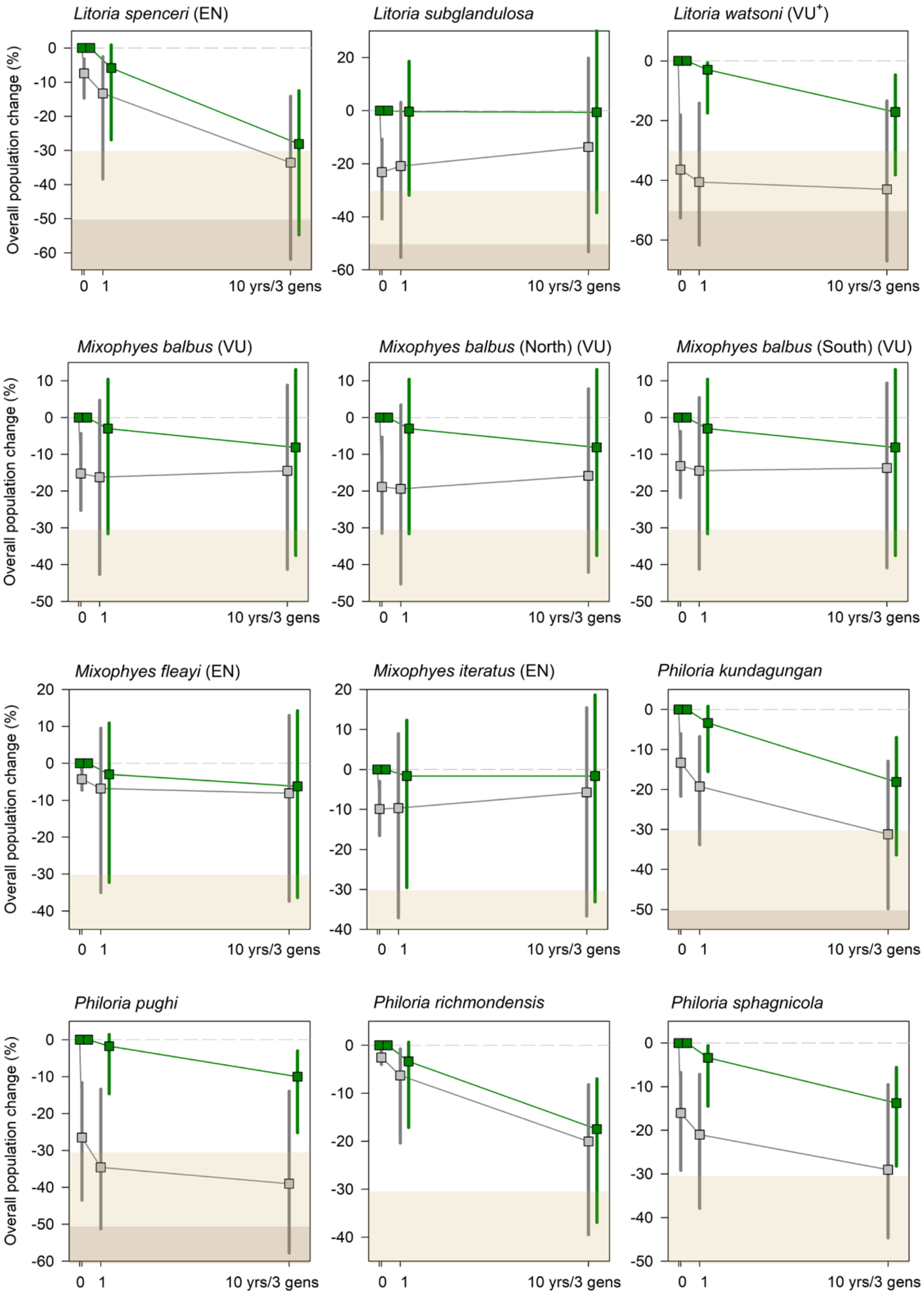


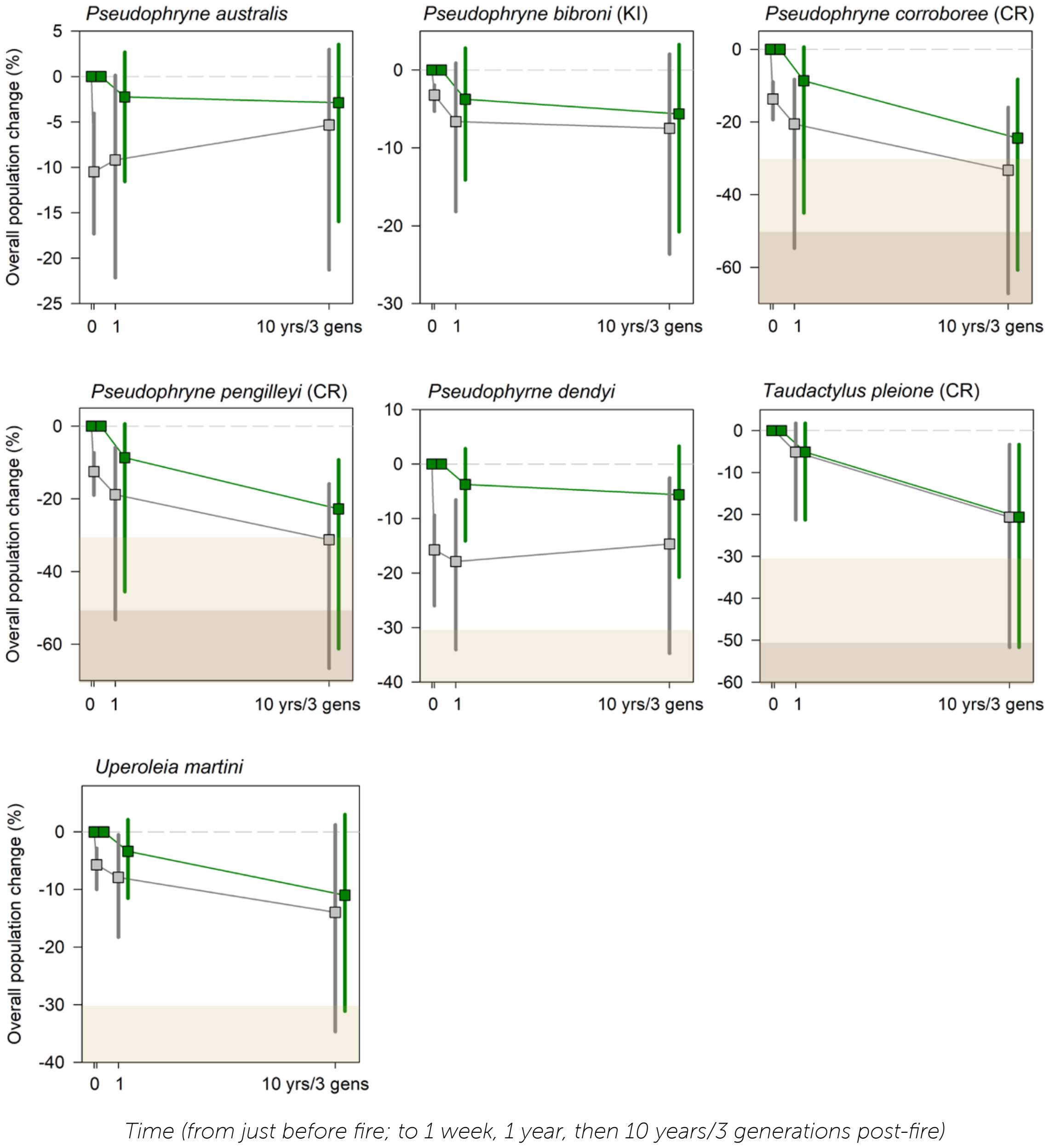
Fig. 23 *The overall population change in 31 frog taxa, 1 week, 1 year and 10 years/three generations after the 2019–20 fires. Taxa are arranged in order of increasing population decline immediately after fire. The estimates are based on combining expert judgement on population response to fires of different severity, with spatial analysis of the proportion of each taxon's range affected by fires of each severity. The graphs show the average estimates and 80% confidence bounds across the expert judgements, and assume current management conditions. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%).*

Fig. 24. (next 3 pages) *Changes in overall population size for each taxon, given the 2019–20 fires (grey lines), and if the fires had not occurred (green lines). Population changes are based on the expert judgements of how each taxon responds to fires of varying severity, combined with the spatial analyses of the proportions of each taxon's range that overlapped with fires of varying severity. Errors represent the average 80% confidence bounds across experts. Both population responses assume no further large-scale fire within the 10 year/3 generation period. Taxa are arranged alphabetically by scientific name. The graphs show the average estimates and 80% confidence bounds across the expert judgements, and assume current management conditions. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%).*

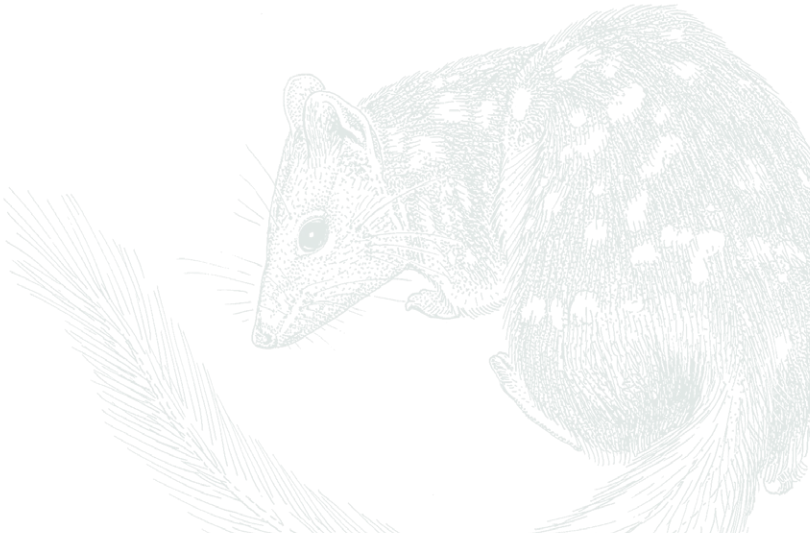




Time (from just before fire; to 1 week, 1 year, then 10 years/3 generations post-fire)



Pseudophryne australis
Overall population change (%)
5
0
-5
-10
-15
-20
-25
0
1
10 yrs/3 gens
Pseudophryne bibroni (KI)
0
-10
-20
-30
0
1
10 yrs/3 gens
Pseudophryne corroboree (CR)
0
-20
-40
-60
0
1
10 yrs/3 gens
Pseudophryne pengilleyi (CR)
Overall population change (%)
0
-20
-40
-60
0
1
10 yrs/3 gens
Pseudophyrne dendyi
10
0
-10
-20
-30
-40
0
1
10 yrs/3 gens
Taudactylus pleione (CR)
0
-10
-20
-30
-40
-50
-60
0
1
10 yrs/3 gens
Uperoleia martini
Overall population change (%)
0
-10
-20
-30
-40
0
1
10 yrs/3 gens
Time (from just before fire; to 1 week, 1 year, then 10 years/3 generations post-fire)



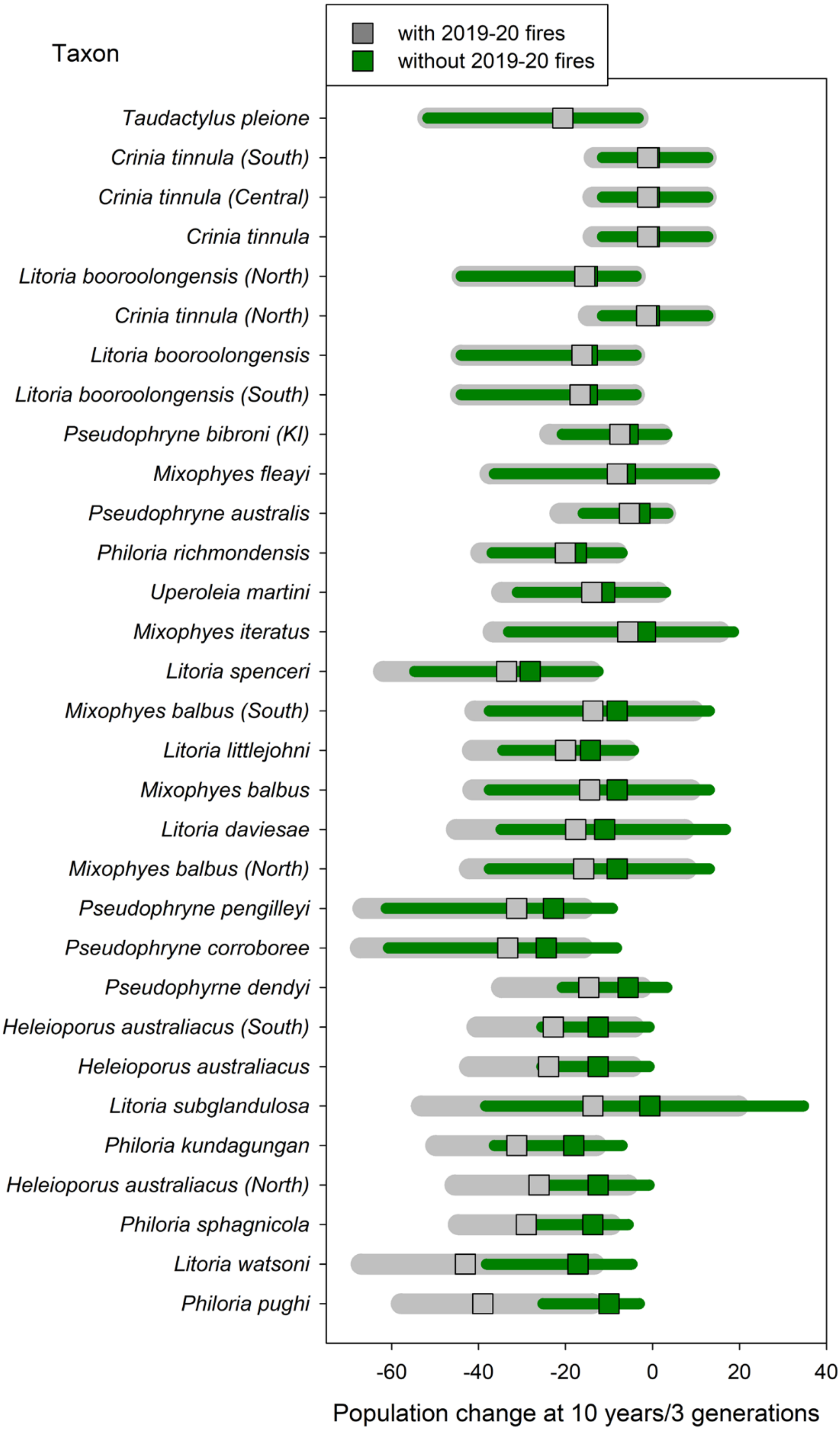


Fig. 25. The legacy effects of the 2019–20 fires, 10 years/three generations later. The graph shows the predicted population change, with 80% confidence bounds, for each taxon given the 2019–20 fires (grey), and if the fires had not occurred (green). Species are sorted on this graph by the magnitude of the legacy effects of fire: these are greater in taxa near the bottom of the graph, where the difference in predictions for overall population change between burnt and unburnt scenarios are largest.

Frogs – priorities for conservation status review

Sixty-three of the 66 taxa considered in this assessment have experienced overall population declines of varying magnitude as a result of the 2019–20 fires; the exceptions are *Taudactylus pleione, Limnodynastes dumerilii insularis* and *Uperoleia mahonyi*, as the spatial analysis found that their distributions did not overlap with the fire extent. These taxa had been included either because their conservation status is very poor and any fire impacts would be material (*T. pleione*), or because the extent of overlap between their distributions and the fires were unclear in the initial assessment.

We estimated the population loss using expert elicitation for 31 of these taxa. The elicitation showed that up to 14 taxa may partially recover over 10 years/three generations, but they will mostly still have diminished populations relative to the size they could have been, had the fires not occurred (Figs. 23, 24). In addition, these predictions assume no further extensive fire events, but climate modelling suggests periods of extreme fire weather will become increasingly common (Williams *et al.* 2009; Di Virgilio *et al.* 2019). Thus, the predictions are likely underestimates, especially for long-lived taxa including the highly impacted *Philoria species, Litoria watsoni, Heleioporus australiacus* and *Litoria subglandulosa* (all >10 years generation lengths). Recurrent fires that occur before full recovery has occurred will gradually culminate in a downward population trajectory.

We reviewed the estimated population change immediately after fire, at one and 10 years/three generations for all taxa included in the expert elicitation, and their current conservation status under the EPBC Act, as well on the IUCN Red List, and in a recent expert assessment (Gillespie *et al.* 2020). We focussed on the most plausible estimate and the lowest 80% confidence bound for the population loss, to develop the following guidelines:

- If the taxon is already listed as CR, it cannot be uplisted because it is already in the highest category of endangerment.
- If the most plausible predicted estimate for population loss any time period exceeds a relevant threshold that would cause the taxon to be listed or uplisted under Criterion A (30% if the taxon is currently unlisted; 50% if currently listed as VU; 80% if currently listed as EN), we recommend the taxon be assessed/re-assessed.
- If the predicted population decline approaches a relevant threshold (i.e. the plausible bounds include the threshold but the most plausible estimate does not exceed it), then:
  - If the taxon is listed (or listed in a higher category) by Gillespie *et al.* (2019) or by the IUCN Red List, but not by the EPBC Act, then this suggests there is evidence of decline additional to the substantial impacts of the 2019–20 fires, and taxon should be assessed/re-assessed.
  - If the taxon is not listed, or not listed at a higher category, by Gillespie *et al.* (2019) or by the IUCN Red List, assessment or re-assessment could still be warranted. For example, if the taxon has a restricted distribution or population size, and has experienced declines as a result of the fire that may continue (given increasing fire frequencies), then the taxon could be eligible for listing under Criteria B or C. This was reviewed case by case.

We also reviewed potential conservation status changes for 35 taxa where we carried out spatial analysis of fire impacts, but did not elicit information on population response to fire. Of these 35 taxa, four are currently listed as Vulnerable under the EPBC Act: *Litoria olongburensis, Litoria aurea, Litoria piperata, Litoria verreauxii alpina*. Of these, the fire overlap was less than 15% for the first taxon. *Litoria olongburensis* meets the eligibility thresholds for listing under Criterion B, and the fire impacts are unlikely to have reduced its distribution sufficiently for it to meet the threshold for listing as Endangered. Over 24% of the distribution of *L. aurea* was burnt; although the fire-caused population loss will be modest, the taxon is listed on the basis of population decline, and the additional population loss caused by the 2019–20 fires may affect its eligibility under Criterion A, so re-assessment should be considered. *Litoria piperata* has not been recorded for over 40 years; it is listed as CR in the IUCN Red List and may be Extinct. Conservation status review would be challenging because of the paucity of records, but we include it for listing re-assessment for consistency. On the basis of published (Banks *et al.* 2020) and unpublished genetic analysis (S. Donellan in 2020) *Litoria verreauxii alpina* may not be a valid taxon; if this is the case, then it should be removed from the list of threatened species.

To make recommendations about conservation review for the remaining 31 taxa, we first examined the relationship between predicted population declines and the fire distributional overlap in taxa for which we had elicited information on population fire response. The population change at one year had a close relationship to the proportion of a taxon's distribution that overlapped with the fire extent, particularly with the extent of severe fire (Fig. 26). These relationships were weaker by 10 years/three generations. The relationship was 'shallow', in that a large proportion of a taxon's range had to be burned in order to cause population declines that might cause that taxon to be eligible for listing.

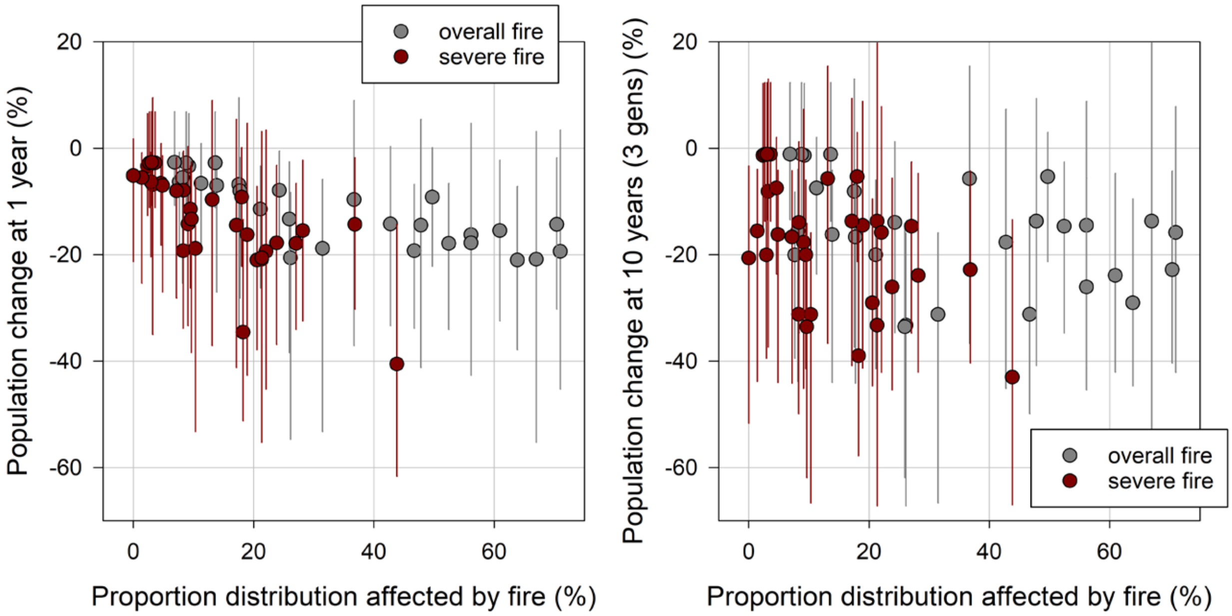


Fig. 26. *The population change, as estimated by experts, for 31 taxa at 1 year (left), and at 10 years (right) against the proportions of their distributions that overlapped with the fire extent (grey) and with severe fires (brown).*

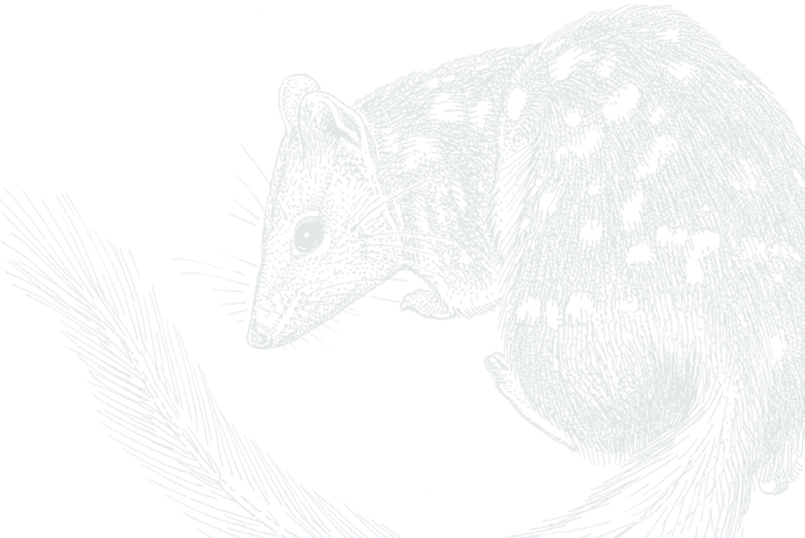
Based on this information, we developed these guidelines for the 31 frog taxa for which we had only fire overlap information:

- Regardless of the fire overlap, if the taxon is listed by Gillespie *et al.* (2019) or by the IUCN Red List, then assessment should be considered.
- If the fire overlap is high (total overlap > 50%; severe fire overlap > 20%), then assessment should be considered. Note there were no range-restricted species in this group, so we did not have to consider potential eligibility against Criterion B.

Using these guidelines to review the conservation assessment priorities across 66 frog taxa, we suggest that the 2019–20 fires have had impacts sufficient to cause seven to 14 previously unlisted taxa (from seven to 14 species) to potentially be eligible for listing as nationally threatened, and to cause 11-12 taxa (from seven to eight species) already recognised as nationally threatened, to be eligible for uplisting (Fig. 27). Thirty-one taxa (from 20 species) taxa are unlikely to qualify for listing, and nine threatened taxa (from seven species) are unlikely to qualify for uplisting (Fig. 27).

Northern corroboree frog (Pseudophryne pengilleyi). *Image: Adam Parsons*

Fig. 27. *A summary of recommendations for conservation status assessments for frogs. Names of taxa that warrant conservation status review are shown in green boxes, and those for which assessment should be considered are in yellow boxes. Species currently listed as threatened that are unlikely to qualify for uplisting are shown in the red box. Species included in the elicitation are marked with an asterisk. The full list of taxa with more detail on the reasons for the recommendations is in Appendix 1c.*



Reptiles - summary

- 45 taxa (40 species) were included in the spatial analysis based on preliminary screening that indicated that fire may have overlapped with their distribution by > 10% if listed, and > 25% if not listed.
  - The taxon with the largest fire overlap (95%) was *Saltaurius kateae*. This narrowly distributed taxon also had the largest value for the proportion of its distribution burnt in a severe fire (43%).
  - Two taxa had low estimates for fire overlap with their distributions: *Liopholis guthega* and *Lampropholis elongata*. They had been included in the analysis out of concern that the overlap of fire with their distributions could be greater than the preliminary mapping indicated.
  - To estimate the fire impacts on the three *Wollumbinia* species, we used the aquatic impacts spatial model.
- We carried out expert elicitation to estimate the local population response to no, mild and severe fires for 30 taxa from 27 species.
  - The taxa predicted to be most adversely affected by severe fire were *Harrisoniascincus zia, Cyclodomorphus praealtus,* and *Lampropholis elongata*, which live in very different habitats.
  - Species that experts considered are relatively protected from the immediate effects of fire, include the rock-dwelling *Hoplocephalus bungaroides* and the turtles, which may escape the immediate impacts of fire but experience declines later if water quality deteriorates.
  - Uncertainty about the local population response to fire increased with increasing time since fire, and was greater for the severe fire scenario than the mild or no fire scenarios.
- We combined the estimates for the proportions of each taxon's distribution affected by each fire class with the expert estimates for local proportional population change when exposed to fire (or aquatic impacts) of varying severity (assuming conditions of current management) to derive estimates of the overall population change in each taxon.
  - The taxon with the largest mean estimate for population decline after fire was *Eulamprus leuraensis* with 25% reduction one week post-fire worsening to a 29% reduction by one year after fire, and then to 33% at 10 years/three generations after fire.
  - In most taxa, the extent of population decline increased between one week and one year after fire, reflecting expert opinion about continued high mortality in the post-fire environment. However, this pattern was not evident in nine taxa, a noticeably higher proportion than in the other terrestrial vertebrate groups.
  - In 14 taxa, the mean estimate for the overall population size is very similar or decreases between one year, and 10 years/three generations post-fire, indicating poor recovery or ongoing decline irrespective of fire (e.g. all *Wollumbinia species, Liopholis guthega, Lissolepis coventryi*).
  - In 25 taxa, population size may recover to some extent between one year and 10 years/three generations in that the 80% confidence bounds around the population estimate at 10 years/three generations included zero (i.e. recovery to pre-fire population size is plausible). In 11 taxa, the mean estimate was close to zero (i.e. within 5% of zero). Again, a higher proportion of reptile taxa plausibly recover by 10 years/three generations compared to mammals, birds, and frogs.
  - The long-term 'legacy' effects of the fire were predicted to be greatest for *Eulamprus leurensis* and *Cyclodomorphus praealtus*. In these taxa, the population size after three generations is predicted to be about 10% less than it would have been had the fires not occurred.
- The reptile taxa in our assessment with fire-affected distributions all experienced population declines as a result of the 2019–20 fires, but the extent of those declines, and the potential for population recovery, is thought to be variable. From reviewing the current conservation statuses in the EPBC Act, the IUCN Red List, and the Reptile Action Plan (Chapple *et al.* 2019), and considering our estimates for population loss as a result of fire, we suggest that one to five listed species may be eligible for uplisting under the EPBC Act, and five to nine species may be eligible for listing.
- The status of four taxa (four species) that are already listed under the EPBC Act has worsened, but either not sufficiently to warrant uplisting, or they are already listed as CR.
- We stress that for a thorough conservation assessment, our estimates for population declines and fire impacts need to be considered in the context of other information on past and future population trajectories, and threat status, for each taxon. Ideally, surveys should be undertaken to provide field data on population status across the range of each taxon, in both fire-affected areas and locations not affected by the 2019–20 fires.

Reptiles - spatial overlaps of fire with distributions

Of the 45 reptile taxa (40 species) in this analysis, the proportion of a taxon's distribution that was burnt ranged up to a maximum of 95%, for *Saltuarius kateae* (Figs. 28, 29; Appendix 1d). This taxon also had the largest value for the proportion of its distribution burnt in a severe fire (43%). Two taxa had low fire values for fire overlap with their distributions: *Liopholis guthega* and *Lampropholis elongata* but were included in the analysis out of concern that the overlap of fire with their distributions could be greater than the mapping indicated.

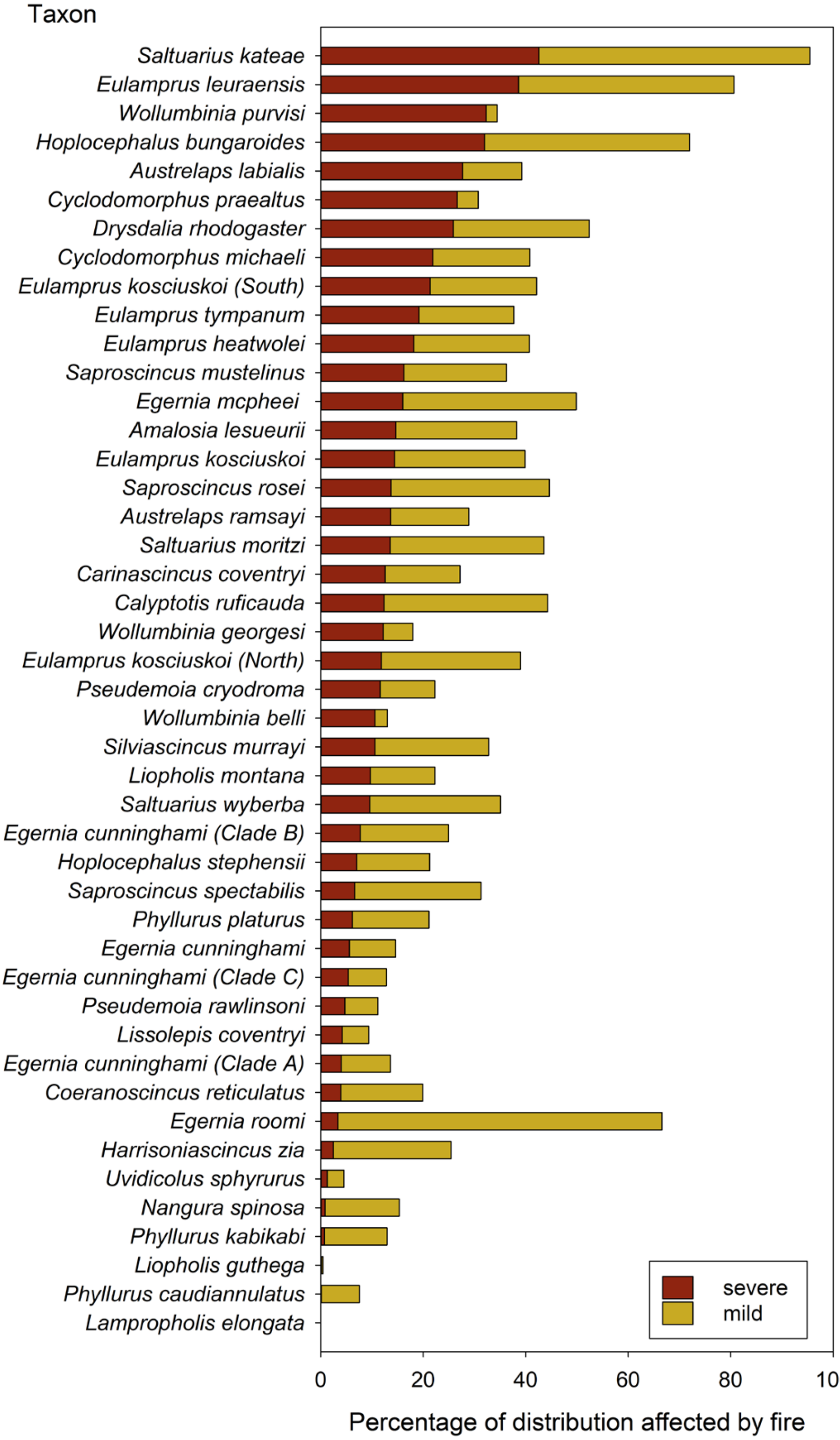


Fig. 28. The proportions of distributional overlap with the extents of severe and mild fire for 45 reptile taxa. Species and constituent subspecies are displayed separately.

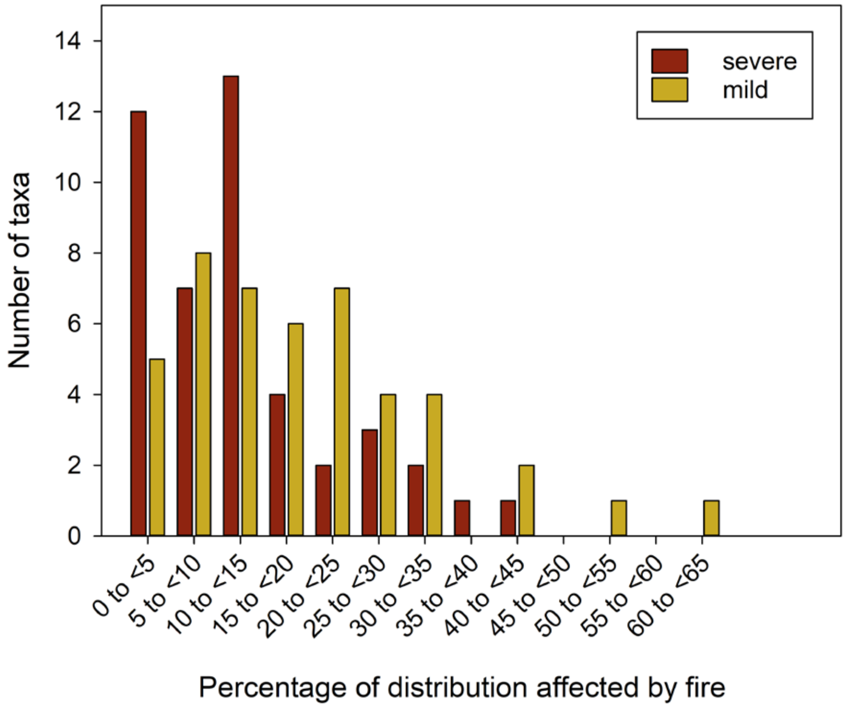


Fig. 29. *The distribution of fire overlap proportions across 45 reptile taxa, displayed for severe and mild fire separately.*

Turtles

The three turtle species in this assessment could be affected by post-fire sedimentation impacts, especially those that are of longer duration or radically change the flow, substrate or structure of the waterway. We explored the implications of using the aquatic impacts model instead of the fire severity map on the proportions of the species' distributions that were affected by fire, and found that the aquatic impacts model produced larger estimates for the distributional overlaps with fire impacts (Table 6). To be conservative, we used the aquatic impacts to estimate the proportion of distributions that were fire-affected (in Figs. 28 and 29) for each turtle species.

Table 6. *Comparison of the proportions of each turtle species' distribution when intersected with the aquatic impacts spatial model and the fire severity mapping.*

Species	Mild aquatic impact (%)	Severe aquatic impact (%)	Extent of aquatic impact (%)	Mild fire extent (%)	Severe fire extent (%)	Fire extent (%)
Wollumbinia purvisi	2.1	32.3	34.4	18.4	9.8	28.0
Wollumbinia belli	2.4	10.6	13.0	6.2	3.2	9.3
Wollumbinia georgesi	5.8	12.2	18.0	15.8	1.1	16.9

Reptiles – expert estimates of local population response to fires of varying severity

Of the 45 reptile taxa included in the spatial analyses, expert elicitation on the local population response to fires of different severity were carried out for 30 taxa from 27 reptile species; these were taxa with the higher fire overlap values, or species with lower fire overlap estimates but with a poor conservation status.

The expert judgements on a taxon's local population changes when exposed to no fire, mild fire and severe fire, from just after the fire (one week), at one year post-fire, and 10 years/three generations post-fire, are summarised in Fig. 30. These estimates assume the continuation of current levels of management. Taxa whose populations are considered to be immediately heavily impacted by severe fire are nearer the bottom of the left-hand panel, and include species with diverse ecologies, such as the rainforest-dwelling *Harrisoniascincus zia*, the alpine grassland-heathland species *Cyclodomorphus praealtus*, and species occurring within eucalypt woodlands such as *Lampropholis elongata*. Species near the top of the graph are those that experts judge are relatively protected from the immediate effects of fire, such as the rock-dwelling *Hoplocephalus bungaroides* and the turtles, which may escape the immediate impacts of fire but experience declines later due to deteriorating water quality.

By one year after fire, the ordering of taxa in terms of the relative population loss begins to re-arrange, and this 'disordering' is marked by 10 years/three generations after fire (the right-hand panel), as the impacts of other threatening processes come into play and affect the population trajectories variously across taxa. In general, the lingering effects of severe fire on population size are relatively more evident at 10 years/three generations than the effect of mild fire at that time point, particularly for the species listed in the bottom half of the graph.

Uncertainty about the local population response increased with increasing time since fire, and was greater for the severe fire scenario than the mild or no fire scenarios (Fig. 30, and see section on Uncertainty overleaf).

*Stephens banded snake (*Hoplocephalus stephensii*). Image: S. Mahony*

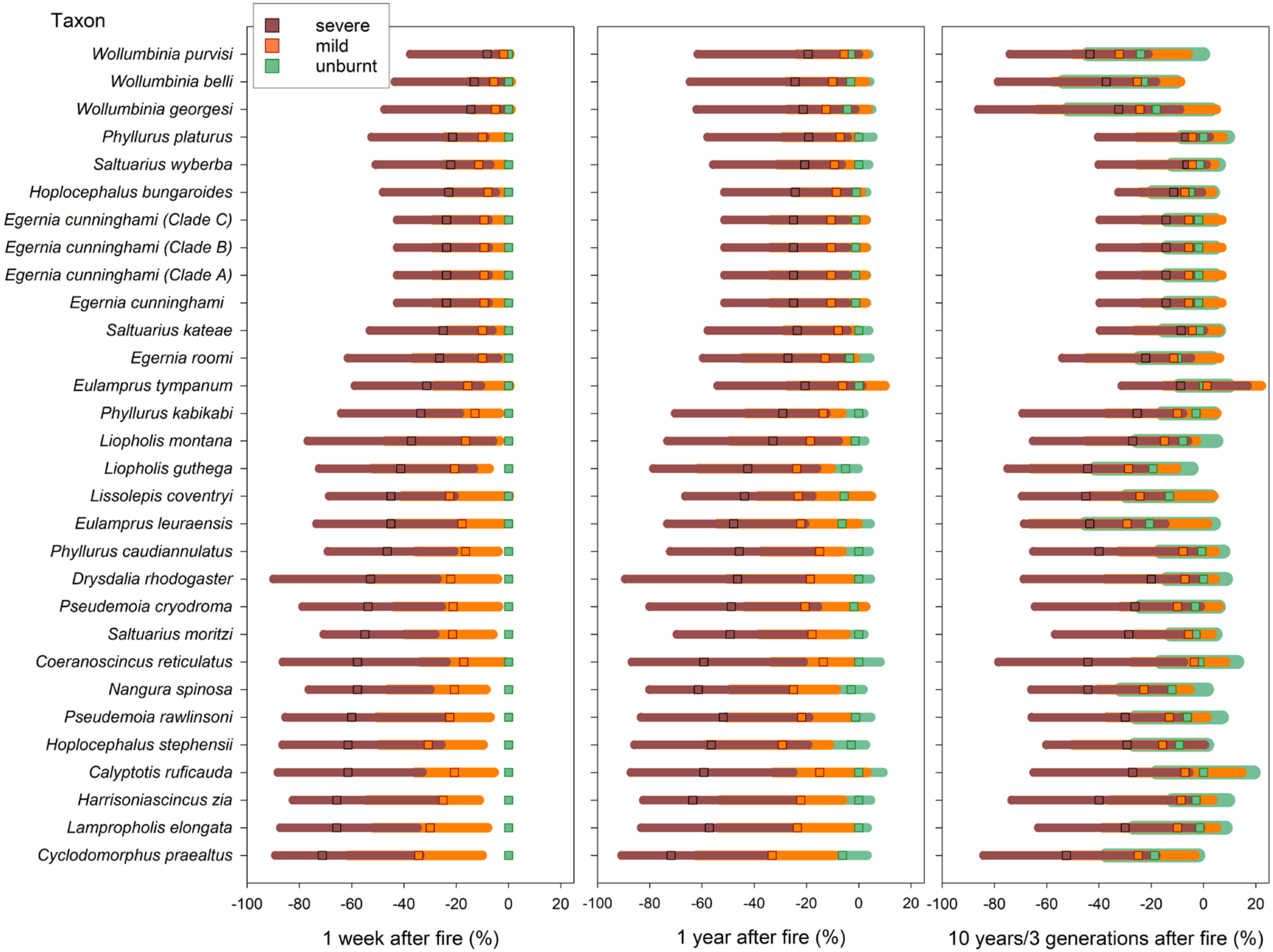


Fig. 30. *The expert judgements on the population changes at a site, from just before the fire, to 1 week, 1 year, then 10 years/3 generations (whichever is longer) after mild fire, severe fire, and no fire at the site. Each bar shows the plausible estimate and the 80% confidence bounds, averaged across experts.*

Reptiles – estimated overall proportional population decline for each species

The expert estimates for proportional population change after fires of varying severity, assuming conditions of current management, were combined with the estimates for the proportions of each taxon's distribution affected by each fire class to derive estimates of the overall population change in each taxon due to the 2019–20 fires. The effects of management, including enhanced management, on population change are explored in a companion report.

The estimates for the overall population change in these taxa at three time points after fire are shown in Fig. 31. The average overall population change across all taxa immediately after the fire equates to a 7% reduction; and ranges from close to zero for *Liopholis guthega* and *Lampropholis elongata* (due to a lack of overlap with the fires, as noted above), to a 25% reduction for *Eulamprus leuraensis*. By one year after fire, the population changes across all taxa averaged an 8% reduction, reflecting that post-fire conditions are expected to cause ongoing mortality. For example, *Eulamprus leuraensis* was again the taxon with the greatest overall population loss, this time with a 29% reduction. By ten years/three generations, the average overall decline was 10%, suggesting limited or no population recovery for many species. The right-hand panel in Fig. 31 shows that whereas some species are expected to recover almost completely within this period (e.g. *Coeranoscincus reticulatus, Saltuarius kateae*), the overall population reduction in other species is similar or increases between one year, and ten years/three generations, post-fire (e.g. *Eulamprus leuraensis, Cyclodomorphus praealatus*). The population predictions at 10 years/three generations for some species, such as the three turtle species and *Liopholis guthega*, were predicted to decline regardless of the fire impacts. Inspection of the 80% confidence bounds suggest that one species may be reduced by 50% one year post fire, and that five species may be reduced by at least 50% by 10 years/three generations post fire. In general, the confidence bounds of estimated population changes for each taxon increased with time after fire (Fig. 31).

The bounds of the population size loss for about two-thirds (22) of the taxa overlap with zero after one year, and 24 taxa have bounds that overlap with zero by 10 years/three generations, suggesting population recovery to 2019–20 levels is possible (Fig. 31). Eleven taxa have estimates for population change at 10 years/three generations that are close to zero (i.e. within 5%), meaning they have returned to their pre-fire populations size. For example, *Eulamprus tympanum, Phyllurus caudiannulatus and Lampropholis elongata*, all which have overall populations at 10 years/three generations <2% lower than their pre-fire sizes, because they have distributions that were minimally affected by the fires (e.g. *Lampropholis elongata*) or because they are predicted to be highly resilient to fire (e.g. *Eulamprus tympanum*).

Sixteen taxa (13 species) had populations at 10 years/three generations that were predicted to have increased relative to their population sizes immediately or one year after fire; all other taxa declined from the post-fire population size over the same interval. Variation in the post fire population trajectories across species could reflect the time required for critical resources to re-establish, differences in management inputs and their effectiveness, or that the taxon is experiencing ongoing decline due to other threats, in some cases with these other threats interacting with fire impacts.

To disentangle any legacy effects of fire on the longer-term population trajectory, we compared the estimates for the overall population change after fire to the estimates for population change in the unburnt scenario, for each taxon (Fig. 32). The differences between the predicted population changes at 10 years/three generations, with and without the 2019–20 fires, are summarised again in Fig. 33. The taxa with the largest population deficit (of around 10%) as a result of the 2019–20 fires were *Eulamprus leurensis* and *Cyclodomorphus praealtus*.

The plots of population trajectories for individual species (Fig. 32) also show clearly that ongoing declines are substantial for several species, regardless of whether the populations were exposed to fire (e.g. *Liopholis guthega, Nangura spinosa* and the three *Wollumbinia* spp).

Note that the expert judgements on the population change after fire included an assumption of no further large-scale fires. However, projections of future climate and fire risk suggests this is unrealistic (Williams *et al.* 2009; Di Virgilio *et al.* 2019). The population curves shown in Fig. 32 are therefore likely underestimates, especially for longer-lived species.

If fire class 2 was grouped with unburnt, rather than with mild fire, the average population decline was reduced by 0.9%, 0.8% and 0.3% immediately, 1 year, and 10 years/three generations after fire respectively. No taxa had estimates for population declines with differences that exceeded 5% in any time period, depending on how fire class 2 was categorised.

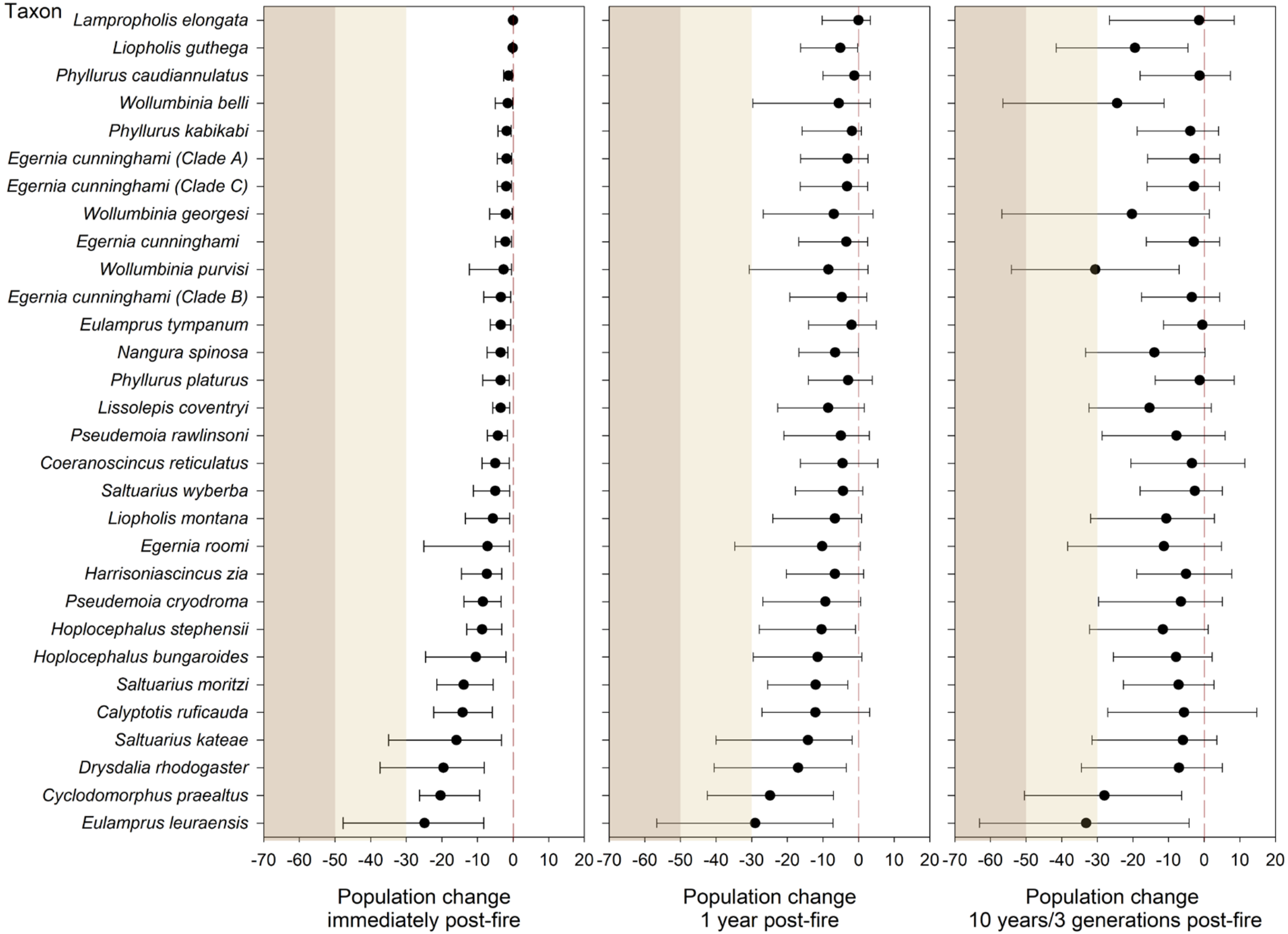
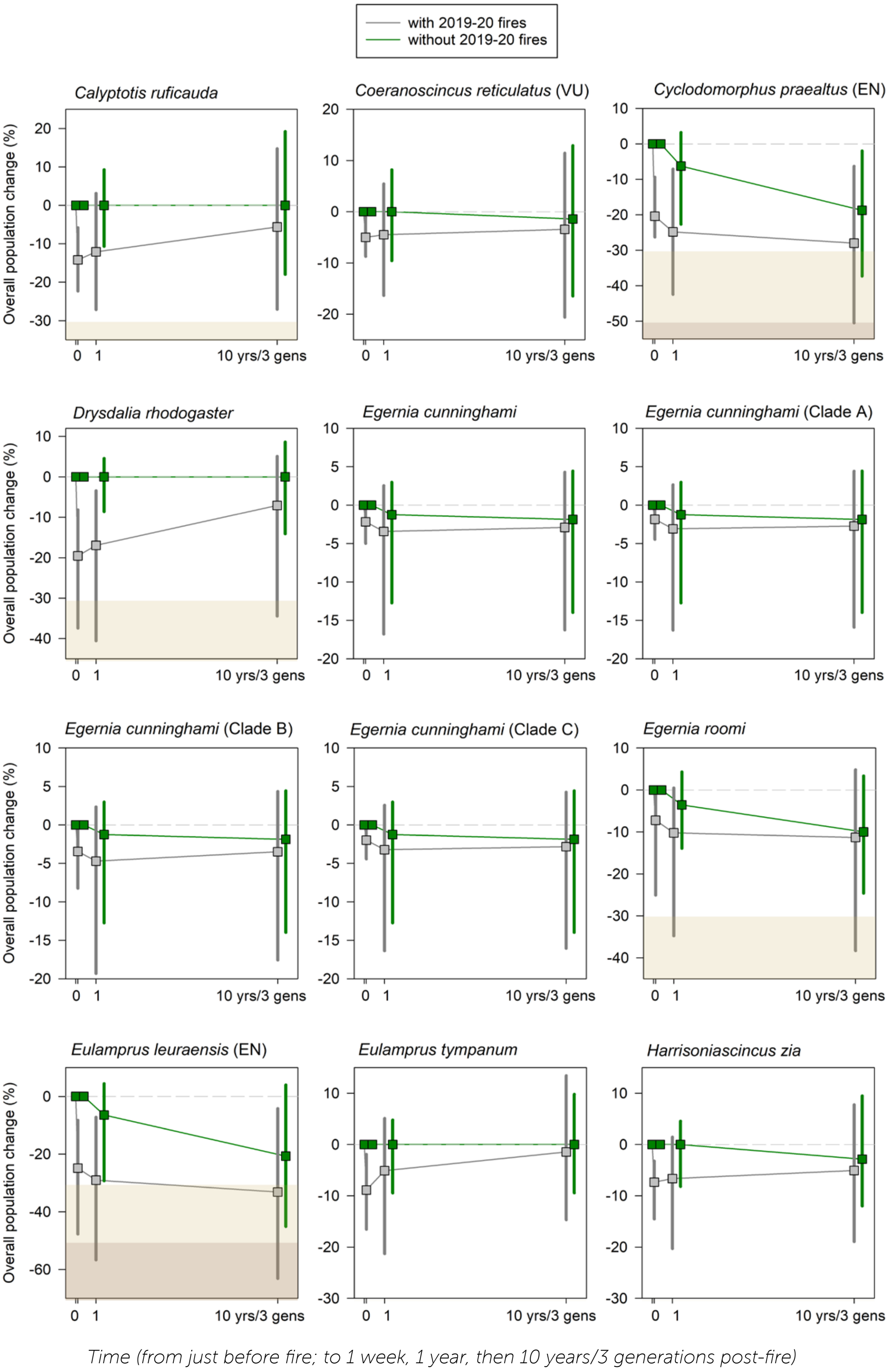
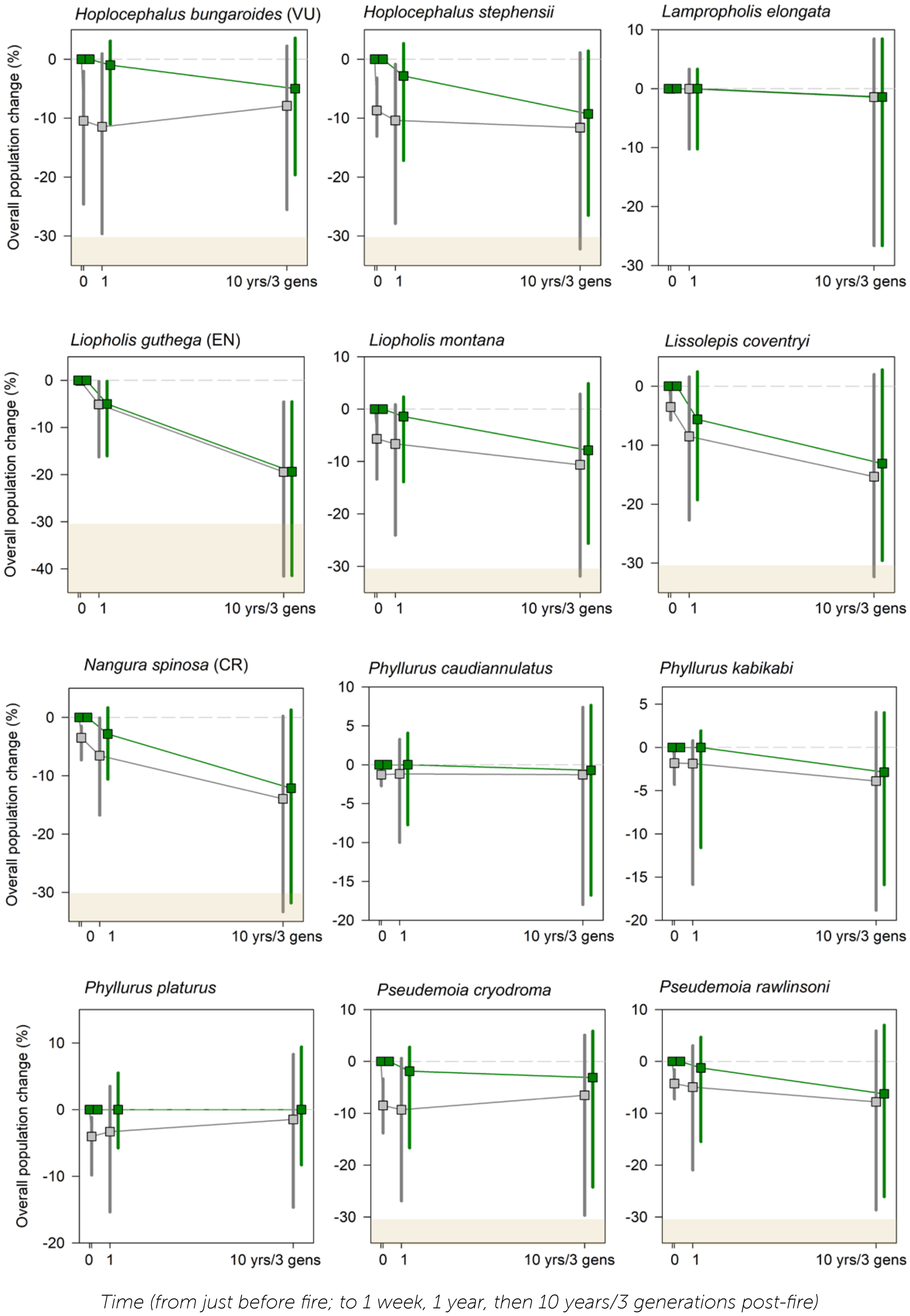
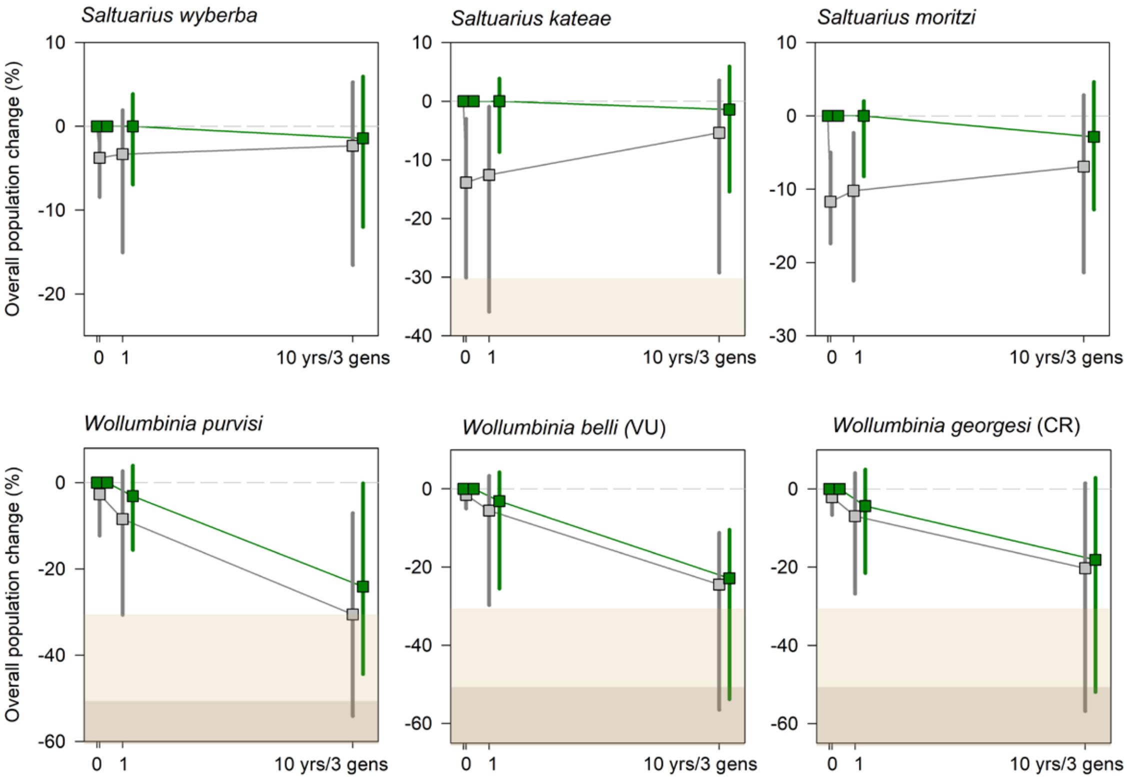


Fig. 31. The overall population change in 30 reptile taxa, 1 week, 1 year and 10 years/three generations after the 2019–20 fires. Taxa are arranged in order of increasing population decline immediately after fire. The estimates are based on combining expert judgement on population response to fires of different severity, with spatial analysis of the proportion of each taxon's range affected by fires of each severity. The graphs show the average estimates and 80% confidence bounds across the expert judgements. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%).

Fig. 32. (next 3 pages) *Changes in overall population size for each taxon, given the 2019–20 fires (grey lines), and if the fires had not occurred (green lines). Population changes are based on the expert judgements of how each taxon responds to fires of varying severity, combined with the spatial analyses of the proportions of each taxon's range that overlapped with fires of varying severity. Errors represent the average 80% confidence bounds across experts. Both population responses assume no further large-scale fire within the 10 year/3 generation period. Taxa are arranged alphabetically by scientific name. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%).*




Hoplocephalus bungaroides (VU)
Hoplocephalus stephensii
Lampropholis elongata
Liopholis guthega (EN)
Liopholis montana
Lissolepis coventryi
Nangura spinosa (CR)
Phyllurus caudiannulatus
Phyllurus kabikabi
Phyllurus platurus
Pseudemoia cryodroma
Pseudemoia rawlinsoni
Overall population change (%)
0
1
10 yrs/3 gens
10
5
0
-5
-10
-15
-20
-30
-40
Time (from just before fire; to 1 week, 1 year, then 10 years/3 generations post-fire)



Time (from just before fire; to 1 week, 1 year, then 10 years/3 generations post-fire)

*Blue Mountains Water Skink (*Eulamprus leuraensis*). Image: S. Mahony*

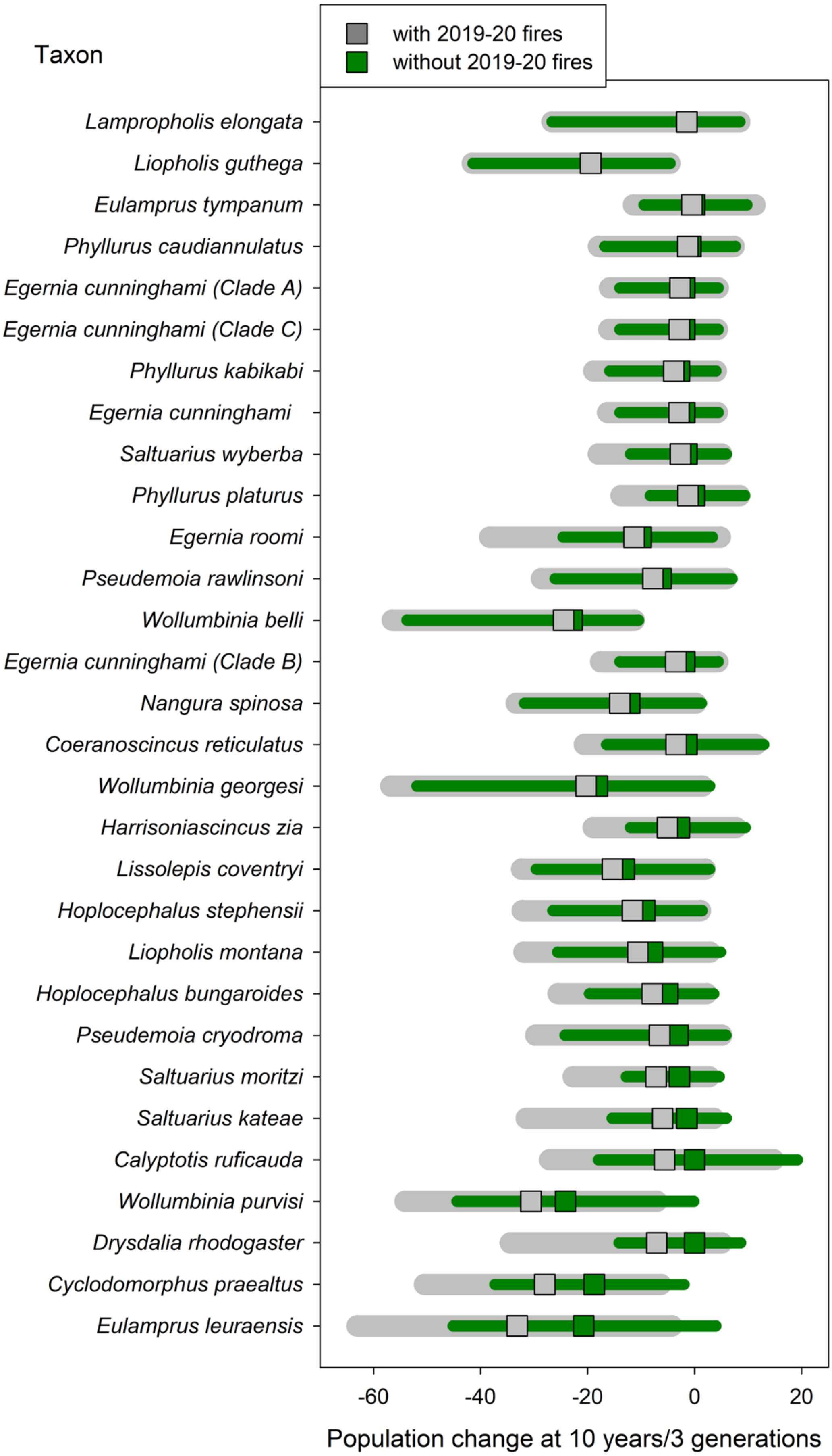


Fig. 33. *The legacy effects of the 2019–20 fires, 10 years/three generations later. The graph shows the predicted population change, with 80% confidence bounds, for each taxon given the 2019–20 fires (grey), and if the fires had not occurred (green). Species are sorted on this graph by the magnitude of the legacy effects of fire: these are greater in taxa near the bottom of the graph, where the difference in predictions for overall population change between burnt and unburnt scenarios are greatest.*

Reptiles – priorities for conservation status review

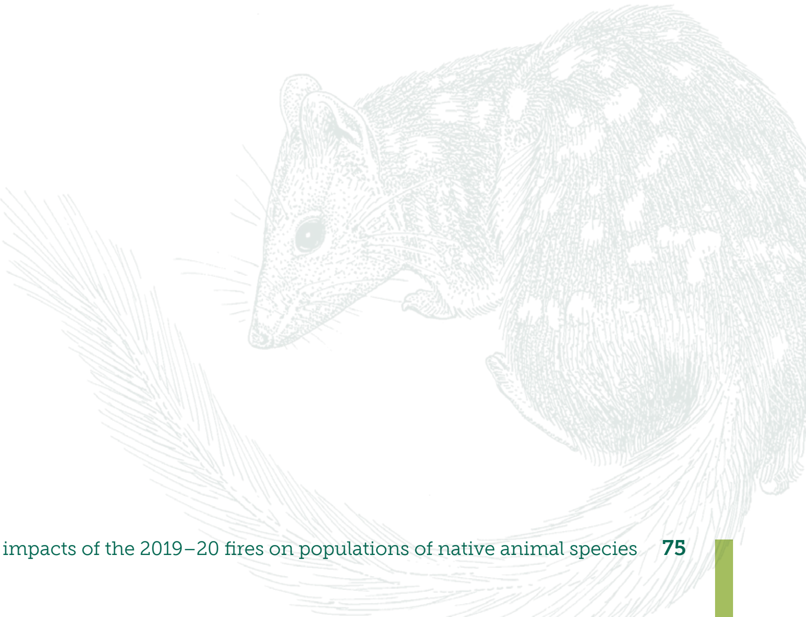
Forty-three of the 45 taxa considered in this assessment experienced immediate overall population declines of varying magnitude as a result of the 2019–20 fires. We estimated the population loss using expert elicitation for 30 of these taxa. The elicitation showed that up to 24 taxa may see recovery in their population size over 10 years/three generations, but many will still have diminished populations relative to the size they could have been, had the fires not occurred (Figs. 31, 32). In addition, these predictions assume no further extensive fire events, but climate modelling suggests periods of extreme fire weather will become increasingly common (Williams *et al.* 2009; Di Virgilio *et al.* 2019). Thus, the predictions are likely to be underestimates, especially for long-lived taxa. Recurrent fires that occur before full recovery has occurred will gradually culminate in a downward population trajectory.

We reviewed the estimated population change immediately after fire, at one and 10 years/three generations for all taxa included in the expert elicitation, and their current conservation status under the EPBC Act, as well on the IUCN Red List, and in a recent expert assessment (Chapple *et al.* 2019). We focussed on the most plausible estimate and the lowest 80% confidence bound for the population loss, to develop the following guidelines:

- If the taxon is already listed as CR by the EPBC Act, it cannot be uplisted because it is already in the highest category of endangerment.
- If the most plausible predicted population decline exceeds a relevant threshold for listing or uplisting (30% if the taxon is currently unlisted; 50% if currently listed as VU; 80% if currently listed as EN), we recommend the taxon be assessed/re-assessed as it may qualify under Criterion A.
- If the predicted population decline approaches a relevant threshold (i.e. the plausible bounds include the threshold but the most plausible estimate does not exceed it), then:
  - If the taxon is listed (or listed in a higher category) in the IUCN Red List (or by another assessment process, such as a state listing process) but not by the EPBC Act, then there is evidence of decline additional to the substantial impacts of the 2019–20 fires, and the taxon should be assessed/re-assessed.
  - If the taxon is not listed, or not listed at a higher category, by the IUCN Red List (or another assessment process), assessment or re-assessment could still be warranted. For example if the taxon has a restricted distribution or population size, and has experienced declines as a result of the fire which may continue (given increasing fire frequencies), then the taxon could be eligible for listing under Criteria B or C. This was reviewed case by case.

We also reviewed potential conservation status changes for 15 taxa where we carried out spatial analysis of fire impacts, but did not elicit information on population response to fire. Of these 15 taxa, *Uvidicolus sphyrurus* is currently listed as Vulnerable under the EPBC Act. Less than 5% of its distribution was burnt, and only 1.2% burned in a severe fire; the fire impacts are therefore unlikely to be sufficient to cause a change in the listing status for this species.

To make recommendations about conservation review for the remaining 14 taxa that are not listed by either the EPBC Act nor the IUCN Red List, we first examined the relationship between predicted population declines and the fire distributional overlap in taxa for which we had elicited information on population fire response. The population change at one year had a close relationship to the proportion of a taxon's distribution that overlapped with the fire extent (Fig. 34). These relationships were weaker after 10 years/three generations. The relationships were 'shallow', in that a large proportion of a taxon's range had to be burned to cause population declines that might cause that taxon to be eligible for listing, reflecting that many individuals in most species survive the fire event.



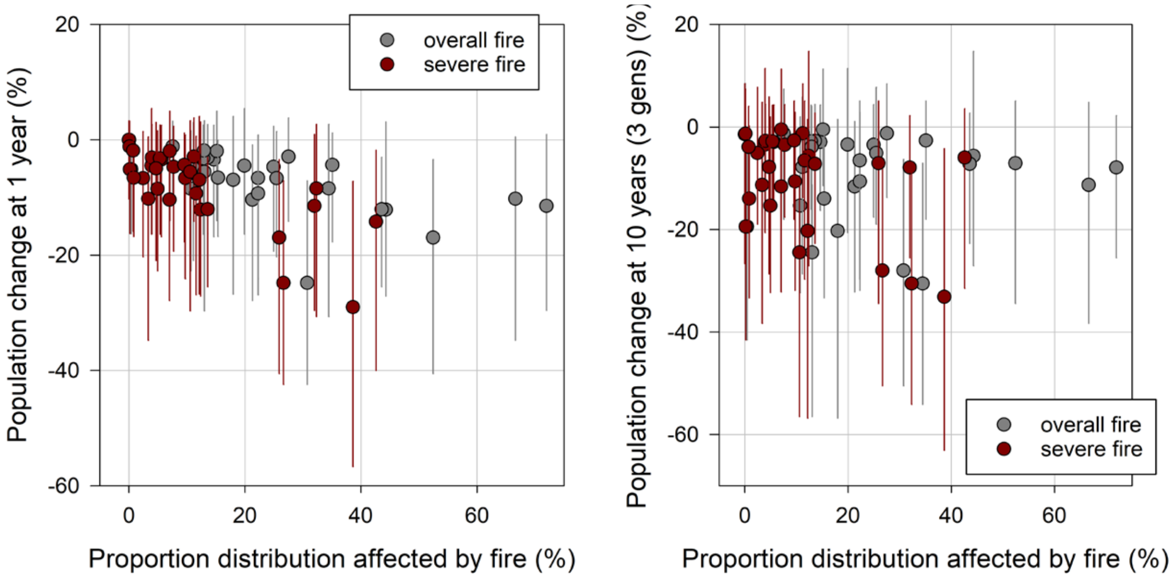


Fig. 34. *The population change, as estimated by experts, for 31 taxa at 1 year (left), and at 10 years (right) against the proportions of their distributions that overlapped with the fire extent (grey) and with severe fires (brown).*

From this information, it seems that for a species to experience at least a 30% overall population decline, at least 30% of its distribution should be burned in a severe fire. However, none of the 14 taxa under consideration experienced severe fire over 30%, suggesting none of them would meet the criteria for listing as Vulnerable under Criterion A. Three taxa (*Austrelaps labialis, Saproscincus spectabilis, Drysdalia rhodogaster*) have small AoO estimates, thus putting Criterion B in scope, but the AoOs are probably underestimates, these taxa are not known to be declining, and there is no reason to think they will not recover post-fire.

Based on these guidelines, we suggest that one to five listed species may be eligible for uplisting under the EPBC Act, and five to nine species may be eligible for listing (Fig. 35). Four additional taxa (*Harrisoniascincus zia, Saltuarius kateae, Saltuarius moritzi, Saltuarius wyberba*) have predicted population declines that do not meet the thresholds for eligibility against Criterion A, but they have very small AoO estimates, putting Criterion B in scope. However, they are all predicted to recover over 10 years/three generations, so the sub criterion of 'continuing decline' is not met. Nevertheless, given their restricted to very restricted geographic distributions, on-ground surveys to check the status of these populations is essential.

Alpine Sheoak Skink (Cyclodomorphus praealtus). *Image: S. Mahony*

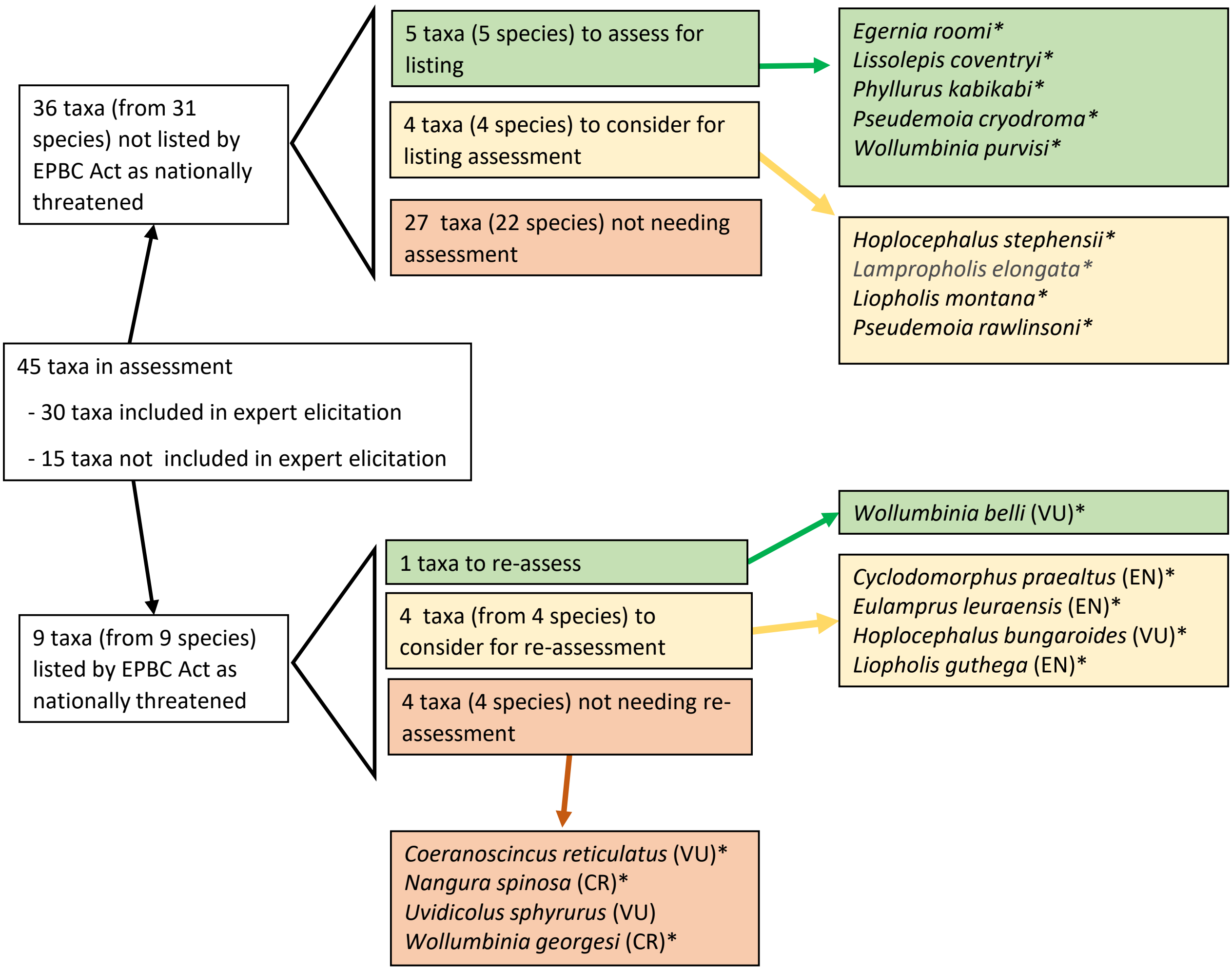
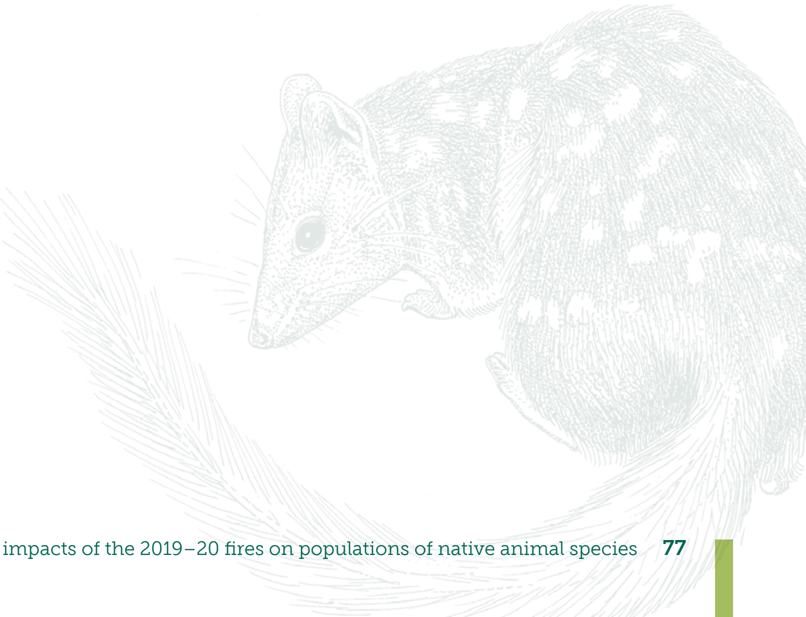
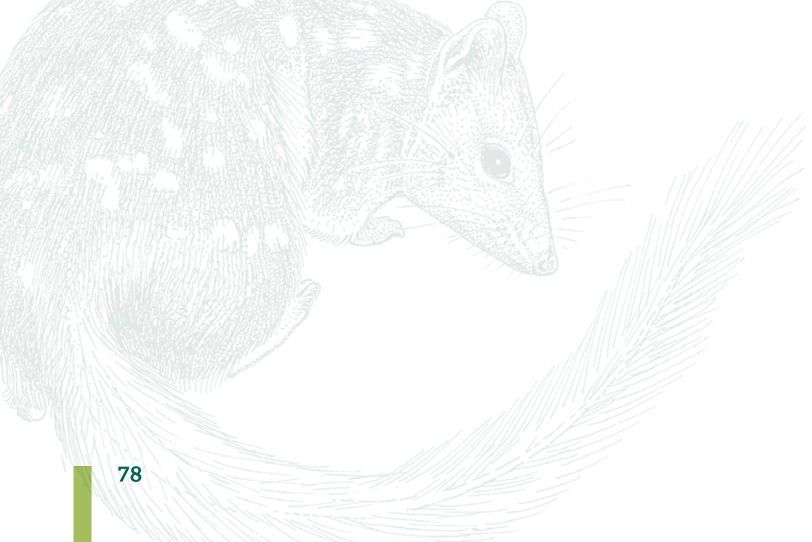


Fig. 35. A summary of recommendations for conservation status assessments for reptiles. Names of taxa that warrant conservation status review are shown in green boxes, and those for which assessment should be considered are in yellow boxes. Species currently listed as threatened that are unlikely to qualify for uplisting are shown in the red box. Species included in the elicitation are marked with an asterisk. The full list of taxa with reasons for the recommendations is in Appendix 1d.



Fish - summary

- 21 fish taxa were included in the spatial analysis based on preliminary screening that indicated that fire may have overlapped with their distribution by > 10%. We used the aquatic impacts model (which combines fire severity and rainfall data with an existing erosion risk model) in this analysis.
  - The taxa with the largest overlap with aquatic impacts (100%) were *Galaxias tantangara, Galaxias aequipinnis, Galaxias* sp. 17 'Cann' and *Galaxias mcdowalli*. Most of their distributions experienced severe risk of aquatic impacts.
- We carried out expert elicitation to estimate the population response to no, mild and severe fires for 16 taxa.
  - The taxa predicted to be most adversely affected by severe fire were several species of *Galaxias*, expected to show immediate population losses of around 40%.
  - The taxon that experts considered was relatively less affected by immediate aquatic impacts after fire was *Maccullochella ikei*.
  - Uncertainty about the local population response increased with increasing time since fire. Unlike other taxa, the uncertainty across the severe, mild and no fire scenarios was similar.
- We combined the estimates for the proportions of each taxon's distribution affected by each aquatic impact class with the expert estimates for proportional population change at sites exposed to aquatic impacts of varying severity (assuming conditions of current management) to derive estimates of the overall population change in each taxon.
  - The taxon with the largest mean estimate for population decline after fire was *Galaxias* sp. 17 'Cann' at 37% reduction one week post-fire. At one year, *Galaxias* sp. nov. 'yalmy' was the taxon with the greatest population loss (54% decline), worsening to a 61% reduction by 10 years/three generations after fire.
  - In all taxa, the extent of population decline increased between one week and one year after fire, reflecting expert opinion that while fish can survive the actual burn, post-fire aquatic impacts can occur weeks and months after fire.
  - In all but one taxon (*Maccullochella ikei*), the mean estimate for the overall population size decreases between one year and 10 years/three generations post-fire, indicating continuing decline.
  - In three taxa, population size may recover to some extent, between one year and 10 years/three generations, in that the 80% confidence bounds around the population estimate at 10 years/three generations included zero (i.e. recovery to pre-fire population size is plausible). In no taxa, was the mean estimate close to zero (i.e. within 5% of zero).
  - The long-term 'legacy' effects of the fire were predicted to be greatest for *several species of Galaxias*, mainly because the proportions of their distributions that were fire-affected were so high. In these taxa, the population size after three generations is predicted to be about 30% less than it would have been, had the fires not occurred.
- The fish taxa in our assessment with fire-affected distributions are all predicted to experience population declines as a result of the 2019–20 fires, but the extent of those declines, and the potential for population recovery, is variable. From reviewing the current conservation statuses in the EPBC Act, the IUCN Red List, and as listed by the Australian Society for Fish Biology (Lintermans 2019), and considering our estimates for population loss as a result of fire, we suggest that one to three listed taxa may be eligible for uplisting under the EPBC Act, and 10 to 12 taxa may be eligible for listing.
- The status of six taxa (five species) that are already listed under the EPBC Act has worsened, but either not sufficiently to cause uplisting, or they are already listed as CR.
- We stress that for a thorough conservation assessment, our estimates for population declines and fire impacts need to be considered in the context of other information on past and future population trajectories, and threat status, for each taxon. Ideally, surveys should be undertaken urgently to provide field data on population status across the range of each taxon, in both fire-affected areas and locations not affected by the 2019–20 fires.



Fish - spatial overlaps of aquatic impacts extent with distributions

Of the 21 fish taxa included in the spatial analysis, the proportion of a taxon's distribution at risk of fire-related aquatic impacts varied up to a maximum of 100%, for *Galaxias tantangara, Galaxias aequipinnis, Galaxias* sp. 17 'Cann' and *Galaxias mcdowalli* (Figs. 36, 37; Appendix 1e). For these taxa, the majority of their distributions were exposed to severe risk of fire-related aquatic impacts. The spatial analysis indicated that one taxon, *Galaxias brevissimus*, had a distribution that did not overlap with the aquatic impacts map. However, expert on-ground knowledge confirmed that about half of the distribution of this fish was significantly burnt. The extent of occurrence for *G. brevissimus* is estimated at 22 km^2, and the area of occupancy at 16 km^2 (IUCN Red List); but clearly the position of the range is incorrectly mapped, illustrating the potential for error when calculating fire overlaps, especially for taxa with very small distributions.

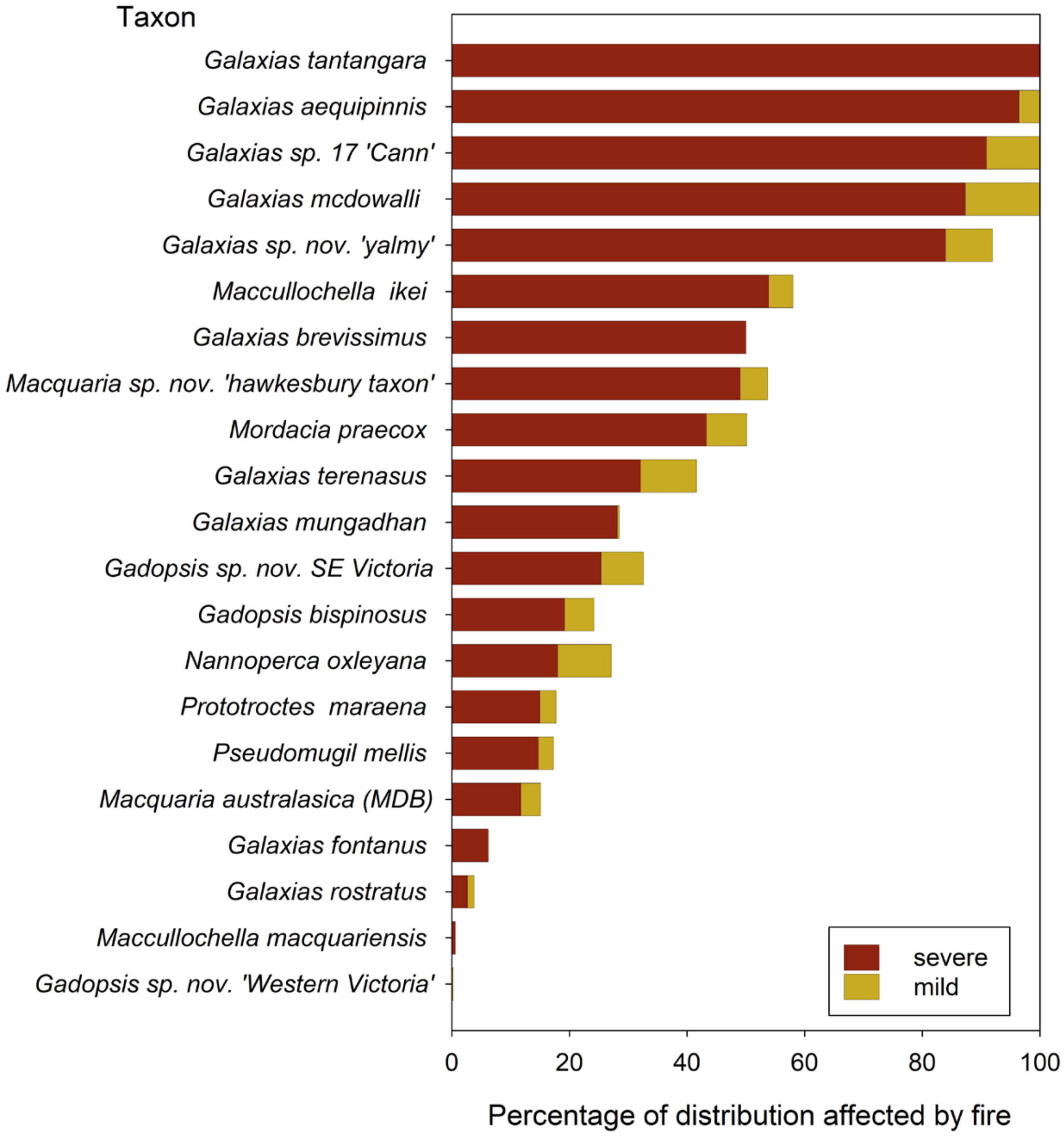


Fig. 36. The proportions of distributional overlap with the extents of severe and mild aquatic impacts for 21 fish taxa.

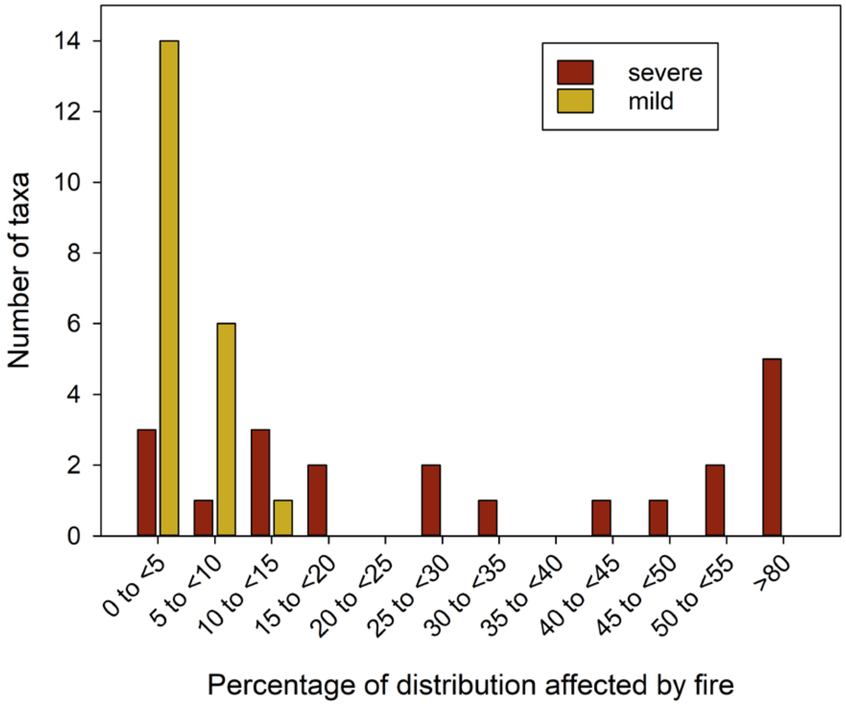


Fig. 37. The distribution of aquatic impacts overlaps with the distributions of 21 fish taxa, displayed for severe and mild fire separately.

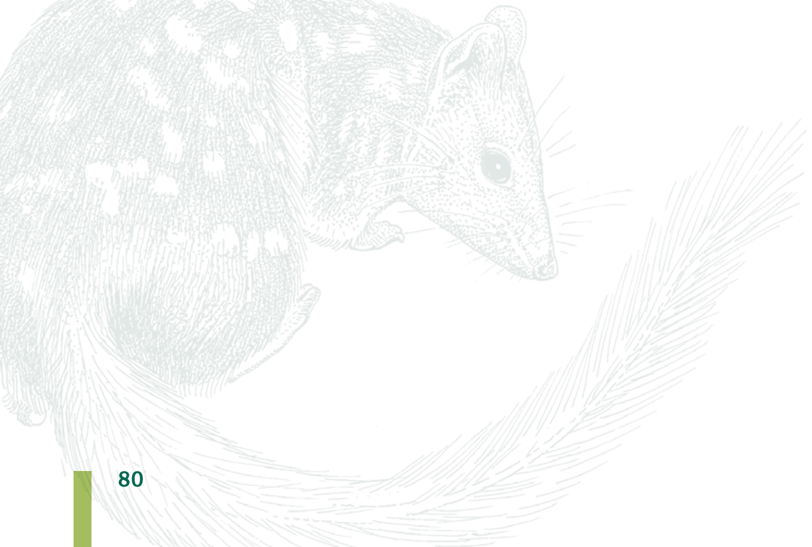
Fish – expert estimates of local population response to fires of varying severity

Of the 21 fish taxa included in the spatial analyses, expert elicitation on the local population response to fire-related aquatic impacts of different severity were carried out for 16 taxa with the higher aquatic impact extent overlap estimates and those with a poor conservation status.

The expert judgements on the local population changes in the event of no, mild and severe aquatic impacts, from just after the fire (one week), at one year post-fire, and 10 years/three generations post-fire, are summarised in Fig. 38. Taxa near the bottom of the left-hand panel, including several species of *Galaxias*, are those that experts considered are most heavily impacted by severe fire-related aquatic impacts, experiencing immediate (one week) population losses of around 40%.

The second panel, which summarises the local population changes at one year after fire, shows that the ordering of taxa in terms of relative fire impacts, are mostly similar to the first panel. However, the size of population loss has generally increased, reflecting expert opinion that mortality rates in the year after fire are elevated for many taxa, mostly because the aquatic impacts (e.g. sedimentation) following fire can occur weeks or months after the fire event itself. By 10 years/three generations, taxa have slightly re-ordered, and the relative differences between populations exposed to severe, mild and no aquatic impacts are still evident, but have diminished, especially for the several taxa near the top of the graph. In no taxa were populations exposed to severe aquatic impacts fully recovered by 10 years/three generations.

Uncertainty about the local population response increased with increasing time since fire. Unlike other taxonomic groups, the uncertainty across the severe, mild and no fire scenarios was similar (Fig. 38, and see section on Uncertainty overleaf).



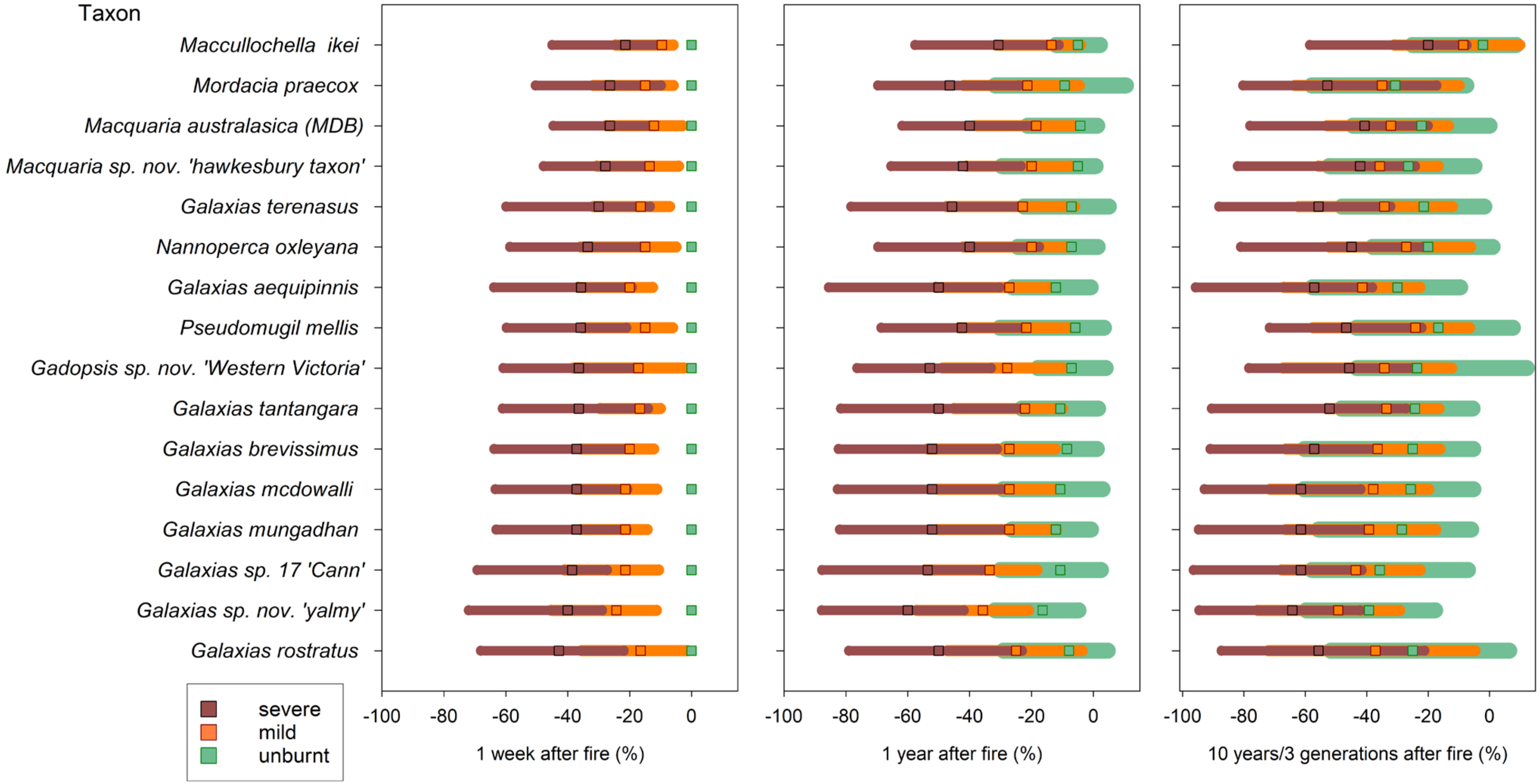


Fig. 38. The expert judgements on the population changes at a site after severe, mild, and no fire-related aquatic impacts; from just before the fire, to 1 week, 1 year, then 10 years/three generations (whichever is longer) after the fire. Each bar shows the plausible estimate and the 80% confidence bounds, averaged across experts.

Fish – estimated overall population decline for each species

The expert estimates for proportional population change after aquatic impacts of varying severity, assuming conditions of current management, were combined with the estimates for the proportions of each taxon's distribution affected by each aquatic impact severity class to derive estimates of the overall population change in each taxon. The effects of management, including enhanced management, on population change are explored in a companion report.

The estimates for the overall population change in these taxa, at three time points after fire, are shown in Fig. 39. The estimates for overall population decline immediately after the fire average to a 16% reduction across all 16 taxa for which elicitation was conducted; and range up to a 37% reduction for *Galaxias* sp. 17 'Cann'. By one year after fire, the population changes across all taxa averaged a 27% reduction, reflecting that in most species, the post-fire aquatic impacts (such as sedimentation pulses) will cause additional mortality. For example, *Galaxias* sp. nov. 'yalmy' was the taxon with the greatest estimated population loss at one year post fire with a 55% reduction, compared to a 36% reduction immediately after the fires. By ten years/three generations, the average overall decline was 37%, reflecting expert opinion that most species will either fail to recover, or that the trajectory will continue to decline. *Galaxias* sp. nov. 'yalmy' had the largest decline by 10 years/three generations, at 61%. Inspection of the 80% confidence bounds suggest that six species may be reduced by 50% one year post fire, and that 11 species may be reduced by at least 50% by 10 years/three generations post fire (Fig. 39). In general, the confidence bounds of estimated population changes for each taxon increased with time after fire (Fig. 39).

Only three taxa had bounds that included '0' (i.e. full recovery) by 10 years/three generations, and only 1 taxon had a population mean estimate that improved between 1 week and 10 years/three generations after fire (*Maccullochella ikei*) (Figs. 39, 40).

Variation in post-fire trajectories among species could reflect the time required for critical resources to re-establish, difference in management inputs and their effectiveness, or that the taxon is experiencing ongoing decline due to other threats. To disentangle any legacy effects of fire-related aquatic impacts on the longer-term population trajectory, we compared the estimates for the overall population change after fire to the estimates for population change in the unburnt scenario, for each taxon. The differences between the predicted population changes at 10 years/three generations, with and without the 2019–20 fires, are summarised across taxa in Figs. 40, 41. The taxa with the largest population deficit (by over 30%) as a result of the 2019–20 fires are several species of *Galaxias*, mainly because the proportions of their distributions that were fire-affected were so high.

Note that the expert judgements on the population change after fire included an assumption of no further large-scale fires or extreme drought. However, projections of future climate and fire risk suggests that this is unrealistic (Williams *et al.* 2009; Di Virgilio *et al.* 2019), so the population recovery estimates are optimistic.

Stocky Galaxias. Galaxias tantangara. Image: Tarmo A. Raadik

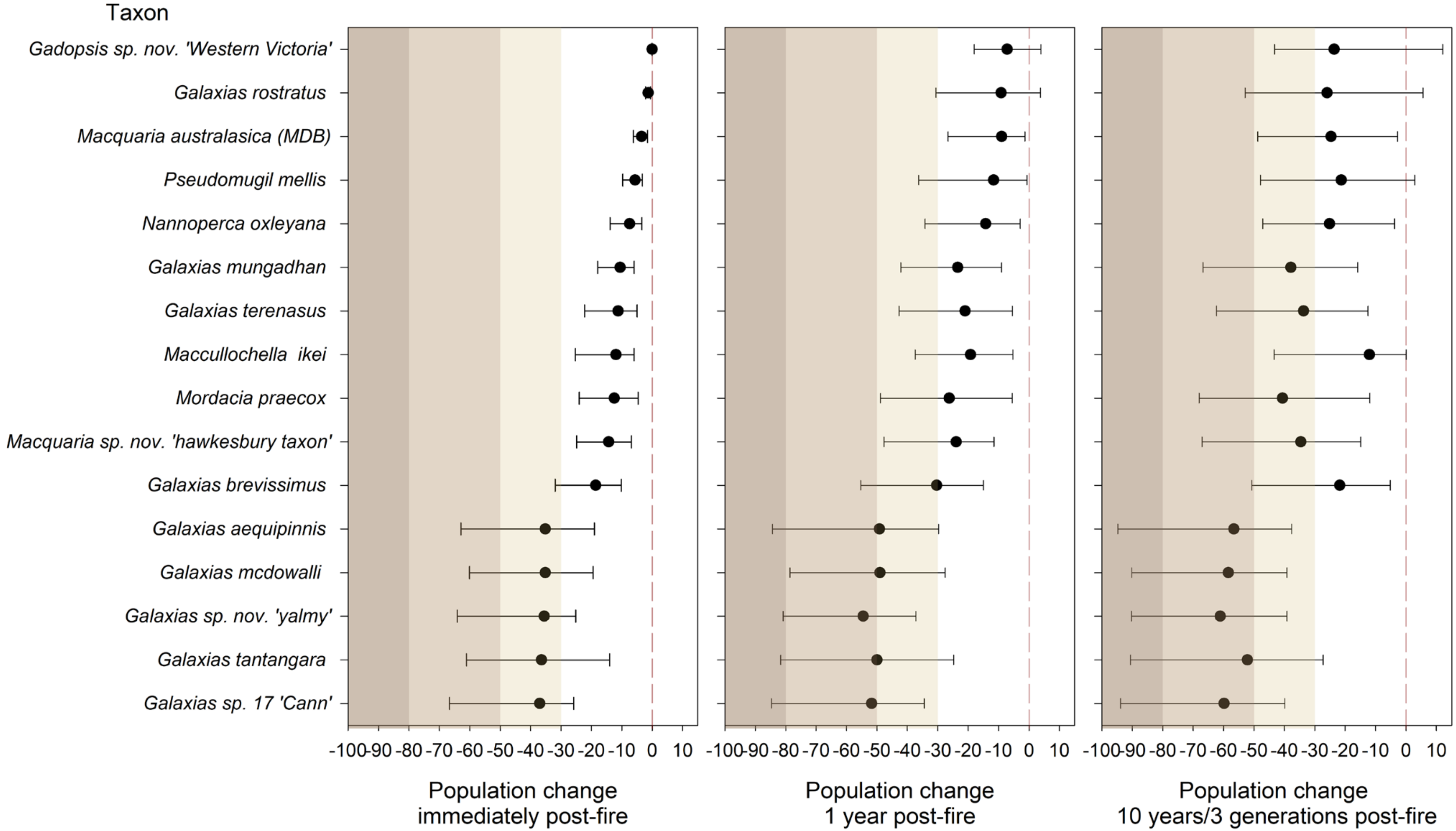
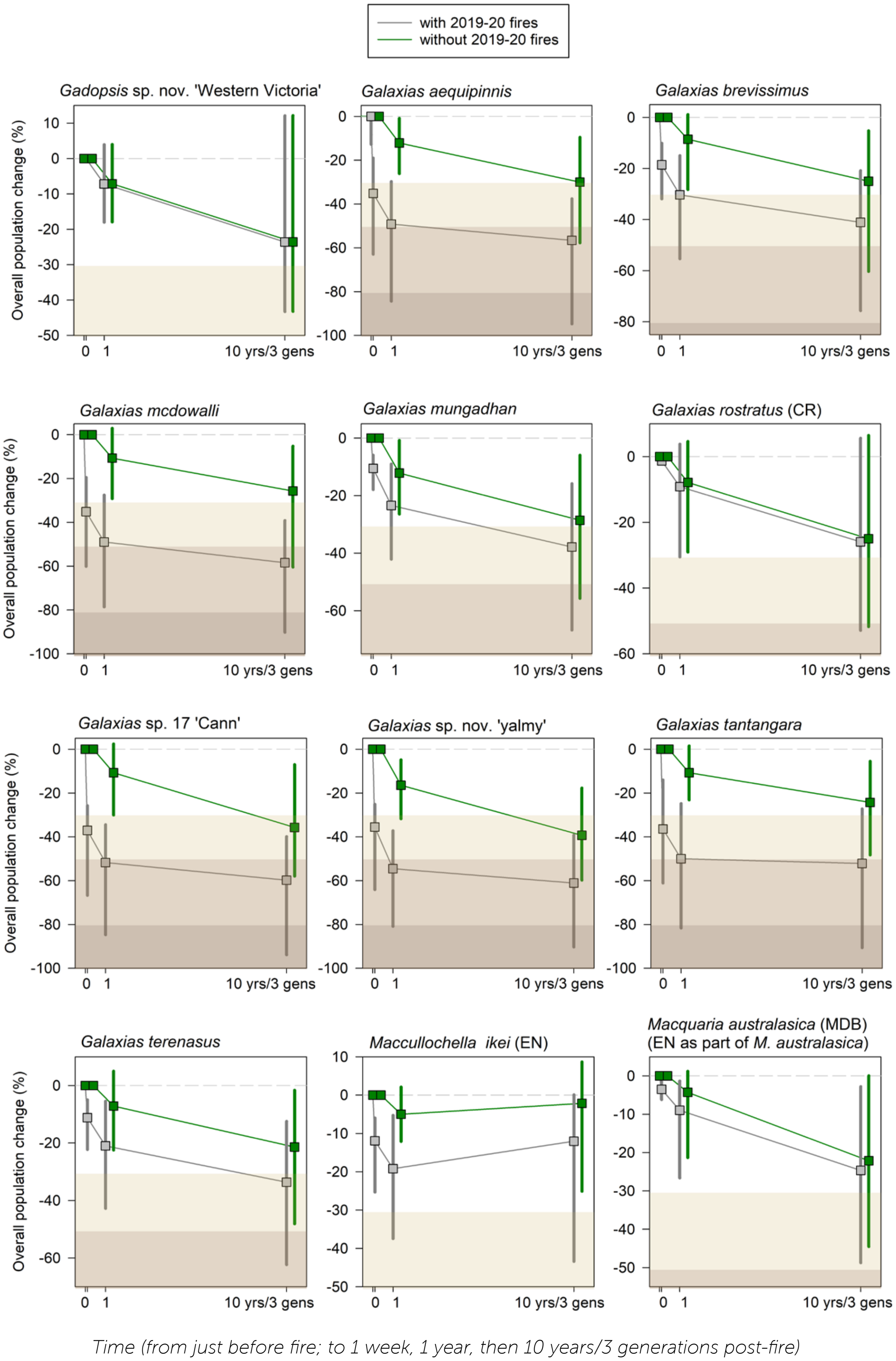
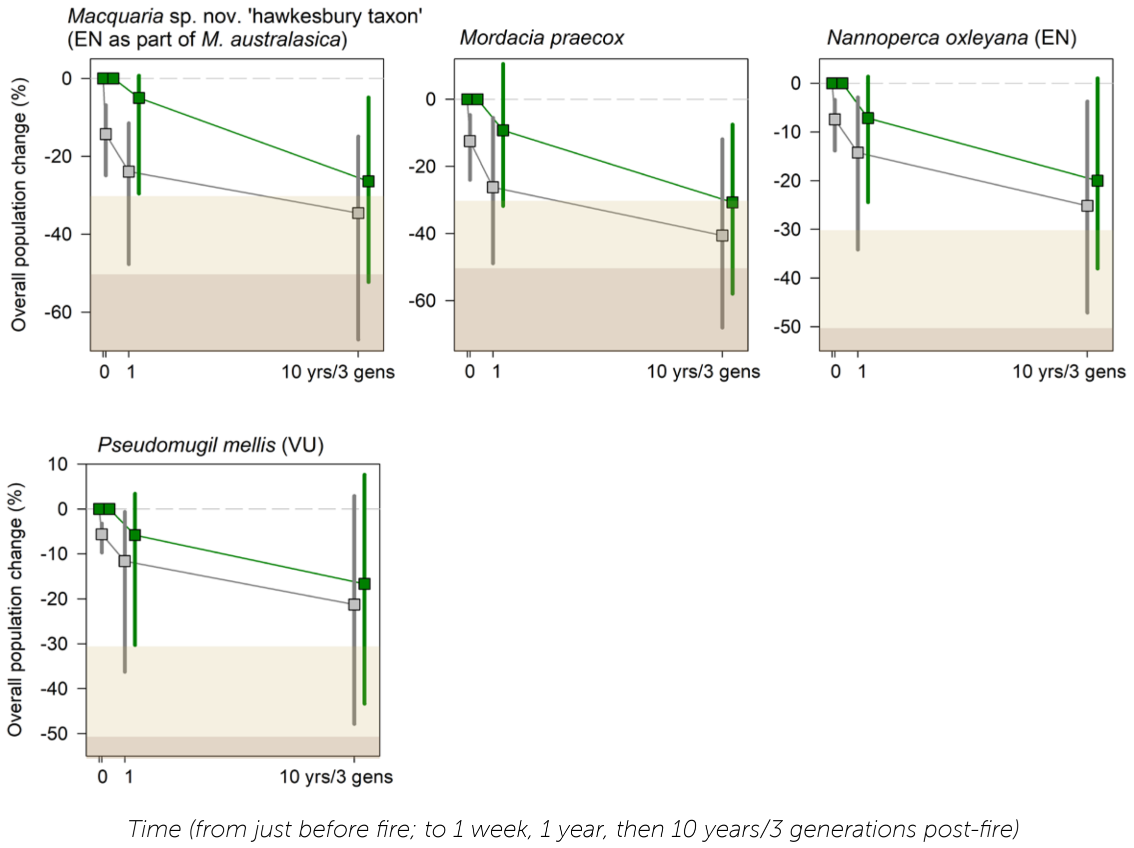


Fig. 39. The overall population change in 16 fish taxa, 1 week, 1 year and 10 years/three generations after the 2019–20 fires. Taxa are arranged in order of increasing population decline immediately after fire. The estimates are based on combining expert judgement on population response to fire-related aquatic impacts of different severity, with spatial analysis of the proportion of each taxon's range affected by severe and mild aquatic impacts. The graphs show the average estimates and 80% confidence bounds across the expert judgements. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%; dark brown is 80%).

Fig. 40. (next 2 pages) *Changes in overall population size for each taxon, given the 2019–20 fires (grey lines), and if the fires had not occurred (green lines). Population changes are based on the expert judgements of how each taxon responds to aquatic impacts of varying severity, combined with the spatial analyses of the proportions of each taxon’s range that overlapped with severe and mild aquatic impacts. Data represent the average estimate and 80% confidence bounds across experts. Both population responses assume no further large-scale fire within the 10 year/three generation period. Species are arranged alphabetically by scientific name. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%; dark brown is 80%).*





Macquaria australasica *(MDB). Image: Mark Lintermans*

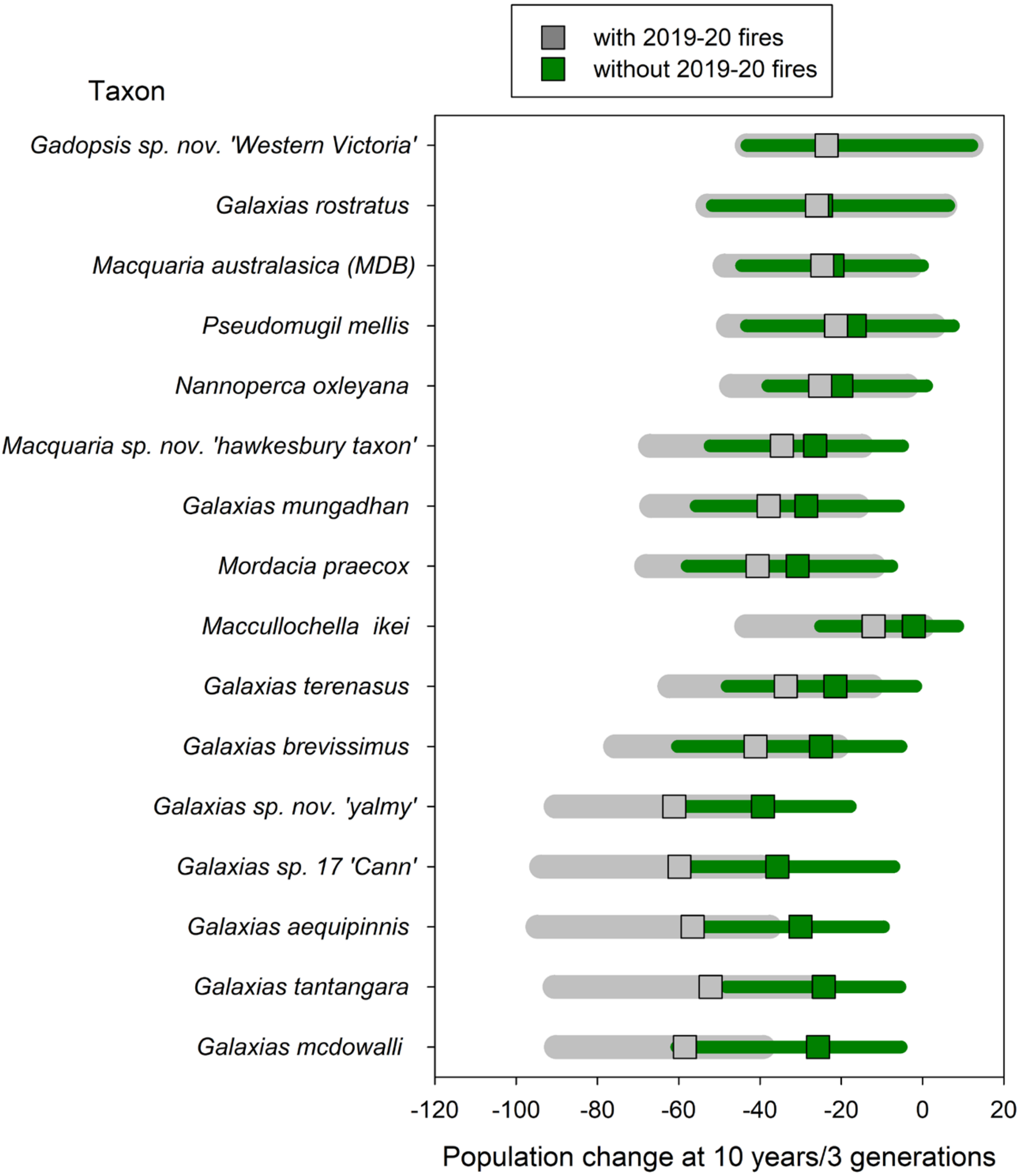


Fig. 41. The legacy effects of the 2019–20 fires, 10 years/three generations later. The graph shows the predicted population change, with 80% confidence bounds, for each taxon given the 2019–20 fires (grey), and if the fires had not occurred (green). Species are sorted on this graph by the magnitude of the legacy effects of fire: these are greater in taxa near the bottom of the graph, where the differences in predictions for overall population change between burnt and unburnt scenarios are largest.

Fish – priorities for conservation status review

Of the 21 fish taxa considered in this assessment, 18 have fire-related aquatic impacts over at least 10% of their distribution, and have experienced overall population declines of varying magnitude as a result. We estimated the population loss using an expert elicitation procedure for 16 of these taxa. The elicitation showed that only one taxon (*Maccullochella ikei*) is likely to increase in population size between one year and 10 years/three generations after the fire, all other taxa continue to decline. In addition, all taxa with >10% distributional overlap with aquatic impacts will still have smaller populations relative to the size they could have been, had the fires not occurred (Figs. 40, 41). These predictions assume no further extensive fire or severe drought events, but climate modelling suggests periods of extreme fire weather will become increasingly common (Williams *et al.* 2009; Di Virgilio *et al.* 2019). Thus, the predictions are likely underestimates, as most of the fish taxa in this assessment are known to be sensitive to drought. Recurrent fires that occur before full recovery has occurred will gradually culminate in a downward population trajectory, especially if they cause permanent changes in stream architecture.

We reviewed the estimated population change immediately after fire, at one and 10 years/three generations for all taxa included in the expert elicitation, and their current conservation status under the EPBC Act, as well on the IUCN Red List, and in a recent assessment by the Australian Society for Fish Biology (Lintermans 2019). We focussed on the most plausible estimate and the lowest 80% confidence bound for the population loss, to develop the following guidelines:

- If the taxon is already listed as CR, it cannot be uplisted because it is already in the highest category of endangerment.
- If the taxon is listed by the IUCN Red List and/or by Lintermans (2019), and is not listed by the EPBC Act, or is listed but at a lower category, then listing assessment or re-assessment is either recommended or should be considered, depending on the extent of listing misalignment and the predicted impacts from the fires. For example, a taxon listed as CR by IUCN, but not listed by the EPBC Act is recommended for assessment regardless of the extent of the fire impacts. A taxon already listed as EN by both the EPBC Act as well as IUCN under Criterion B, with modest fire impacts, is unlikely to qualify for uplisting under Criterion A, and would only be eligible for uplisting under Criterion B if that population decline could reduce the AoO or EoO below the threshold for CR.

For taxa not included in the elicitation, we first examined the proportion of the distribution affected by aquatic impacts and found there is a strong relationship between the proportion of a taxon's distribution affected by aquatic impacts and the extent of its population decline (Fig. 42). For taxa in our assessment (not part of the elicitation) if the aquatic impacts proportion was greater than 30% or there was evidence of pre-fire decline, we recommend listing assessment be considered.

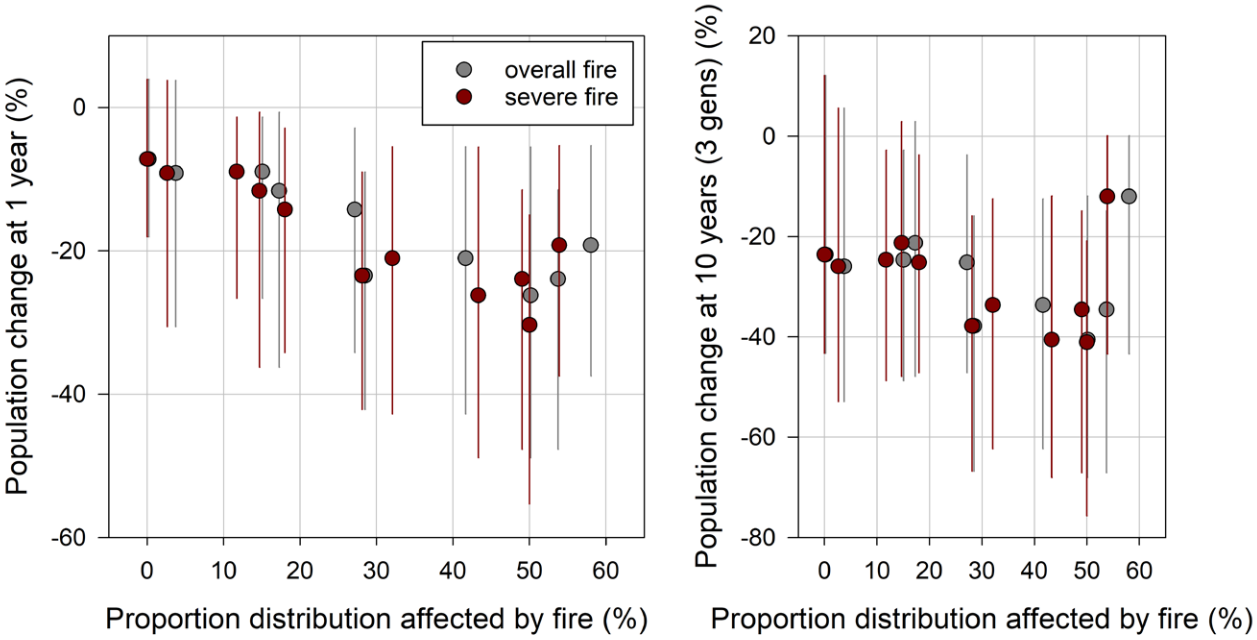


Fig. 42. *The population change, as estimated by experts, for 16 fish taxa at 1 year (left), and at 10 years (right) against the proportions of their distributions that overlapped with aquatic impacts (grey) and with severe aquatic impacts (brown).*

Based on these guidelines, we suggest that one to three EPBC Act-listed species may be eligible for uplisting, and 10 to 12 species may be eligible for listing. Six taxa already listed under the EPBC Act have experienced fire impacts that have worsened their conservation status, but they are either unlikely to be eligible for uplisting, or they are already listed as CR (Fig. 43).

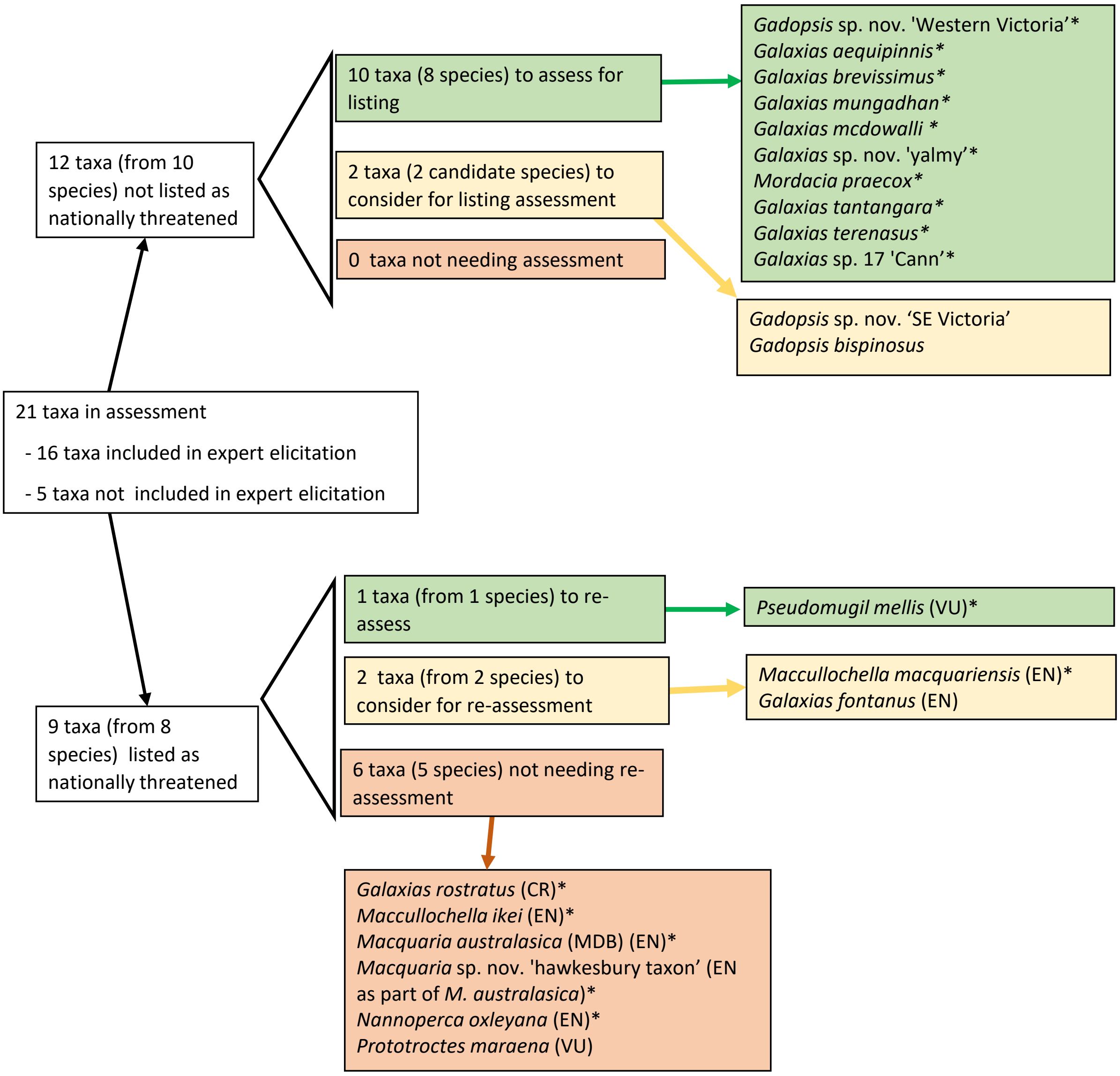
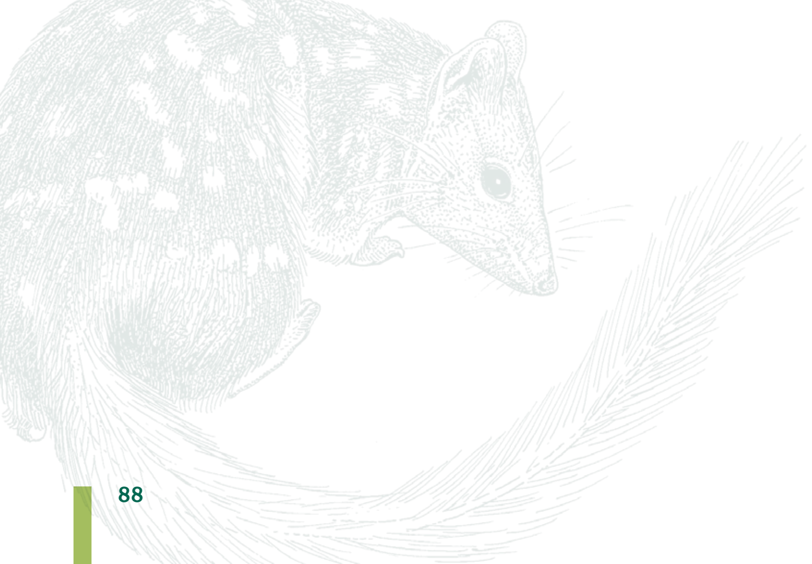


Fig. 43. A summary of recommendations for conservation status assessments for fishes. Names of taxa that warrant conservation status review are shown in green boxes, and those for which assessment should be considered are in yellow boxes. Species currently listed as threatened that are unlikely to qualify for uplisting are shown in the red box. Species included in the elicitation are noted with asterisks. The full list of taxa with reasons for our recommendations for conservation status is in Appendix 1e. Note that since this work was initiated, Galaxias tantangara *has been assessed under the EPBC Act and listed as CR on 3 March 2021.*



Spiny crayfish - summary

- 32 spiny crayfish taxa (32 species) were included in the spatial analysis based on preliminary screening that indicated that fire may have overlapped with their distribution by > 10% if listed, and > 25% if not listed. We used the aquatic impacts model in this analysis for species with burrows attached to waterways, and the fire severity mapping for species with other burrow types.
    - The species with the largest overlap with aquatic impacts (100%) were *Euastacus guwinus* and *Euastacus clarkae*. Most of their distributions were affected by severe impacts.
    - The distribution of *Euastacus dalagarbe* did not overlap with any areas of aquatic impact. It had been included in the analysis out of concern that the overlap of fire with its distribution could be greater than the preliminary mapping indicated.
- We carried out expert elicitation to estimate the local population response to no, mild and severe fire (or aquatic impact) for 25 taxa (25 species).
    - The species predicted to be most adversely affected by severe fire were *Euastacus diversus, Euastacus clarkae, Euastacus jagara, Euastacus* sp. 1, *Euastacus* sp. 2, and *Euastacus* sp. 3, all expected to show immediate population losses of over 40% when exposed to severe fire or aquatic impacts.
    - Species with burrows connected to the waterway may be more impacted by fire than species with burrows independent of waterways.
    - The species that experts judged were relatively protected from the immediate impacts of fire (or aquatic impacts) included *Euastacus suttoni* and *Euastacus bidawalus*.
    - Uncertainty about the local population response increased with increasing time since fire and was greater for the severe fire scenario that the mild and no fire scenarios.
- We combined the estimates for the proportions of each species distribution affected by each fire (or aquatic) severity class with the expert estimates for local proportional population change at sites exposed to fire (or aquatic impacts) of varying severity (assuming conditions of current management) to derive estimates of the overall population change in each species.
    - *Euastacus clarkae* had the largest mean estimate for population decline one week after fire, at 44%. At one year, *E. clarkae* was still the species with the greatest population loss (56%). But by 10 years/three generations, *Euastacus* sp. 2 was the most reduced species, with a 46% reduction relative to its pre-fire population size.
    - In all species, the extent of population decline increased between one week and one year after fire, reflecting expert opinion that post-fire aquatic impacts, such as sedimentation events, can continue to occur weeks and months after fire.
    - In all but two species (*Euastacus morgani, Euastacus jagabar*), the mean estimate for the overall population size increases between one year and 10 years/three generations post-fire, indicating some recovery was anticipated.
    - However, only one fire-affected species, *Euastacus neohirsutus*, is predicted to potentially recover to pre-fire levels by 10 years/three generations, in that the 80% confidence bounds around the population estimate at 10 years/three generations included zero (i.e. recovery to pre-fire population size is plausible). This was also the only fire-affected species with a mean estimate close to zero (i.e. within 5% of zero) at 10 years/three generations. This prediction is consistent with the spatial analysis that indicated that this species was only minimally affected by fire (mild fire impacts in 1% of its distribution).
    - The long-term 'legacy' effects of the fire were predicted to be greatest for *Euastacus guwinus, E. clarkae*, and *E.* sp. 2, mainly because the proportions of their distributions that were fire-affected were so high. In these species, the population size after three generations is predicted to be about 40% less than it would have been, had the fires not occurred.
- The spiny crayfish species in our assessment with fire-affected distributions all experienced population declines as a result of the 2019–20 fires, but the extent of those declines, and the potential for population recovery, is variable. By considering the current conservation status on the IUCN Red List, and our estimates for population loss as a result of fire, we suggest that 21 to 25 species of spiny crayfish may be eligible for listing under the EPBC Act.
- We stress that for a thorough conservation assessment, our estimates for population declines and fire impacts need to be considered in the context of other information on past and future population trajectories, and threat status, for each species. Ideally, surveys should be undertaken to provide field data on population status across the range of each species, in both fire-affected areas and locations not affected by the 2019–20 fires.

Spiny crayfish - spatial overlaps of fire and aquatic impacts with distributions

Of the 32 spiny crayfish species included in the spatial analysis, the proportion of a species distribution at risk of fire-related aquatic impacts varied up to a maximum of 100%, with *Euastacus guwinus* having 100% of its distribution affected by severe fire or severe aquatic impacts (Fig. 44; Appendix 1f). The distribution of fire extent values across taxa is shown in Fig. 45.

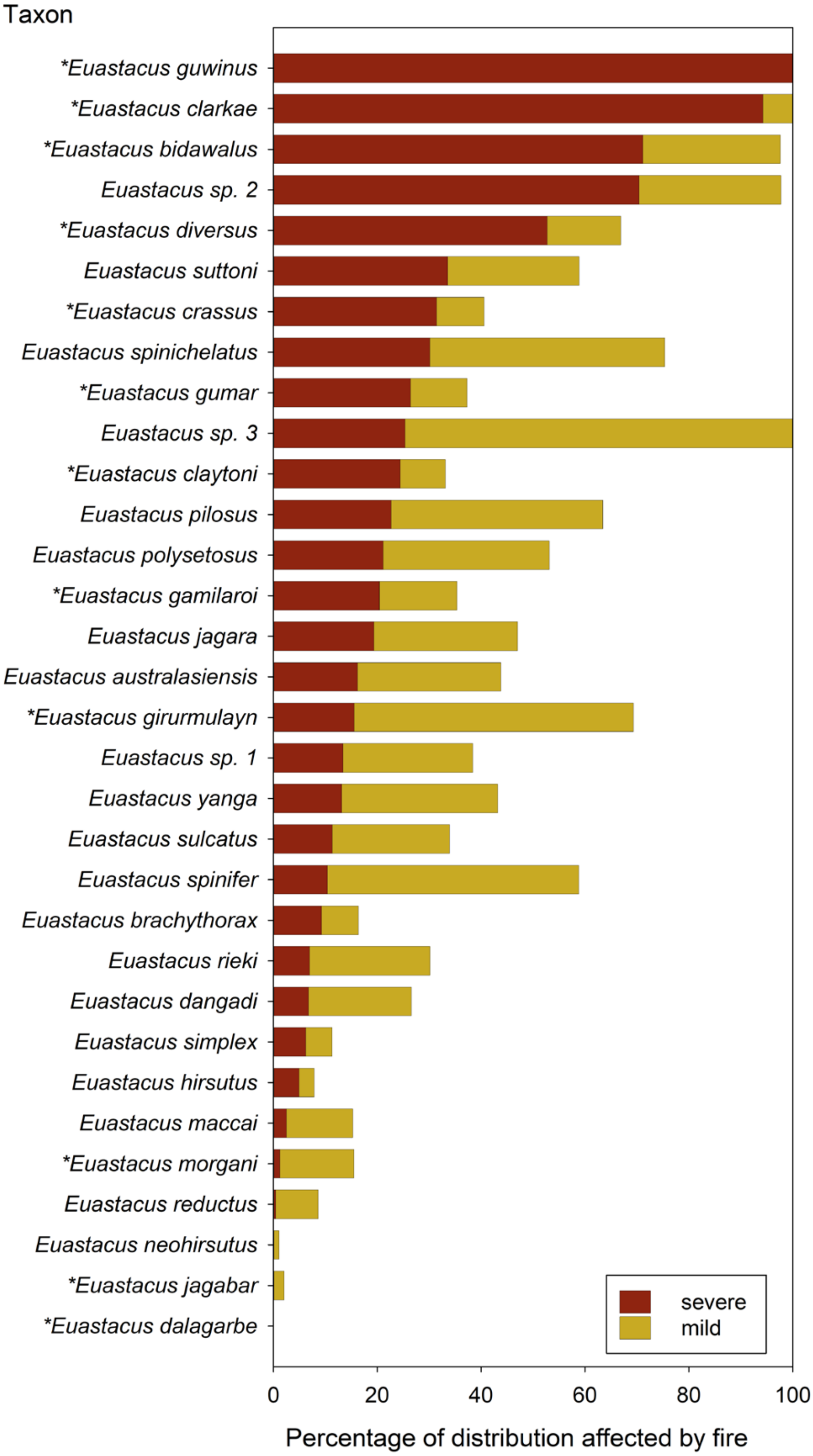


Fig. 44. *The proportions of distributional overlap with the extents of severe and mild fire, and/or severe and mild aquatic impacts for 32 spiny crayfish taxa. Species with burrows connected to the stream, and which can therefore experience aquatic impacts, are shown with an asterisk.*

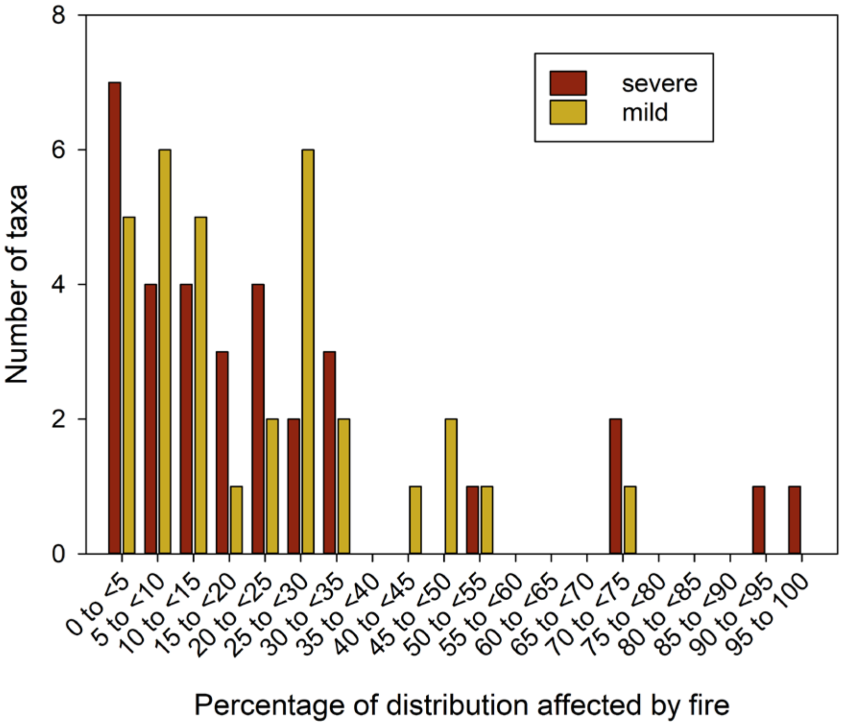


Fig. 45. *The distribution of fire severity impact, and aquatic impact overlaps with the distributions of 32 spiny crayfish taxa, displayed for severe and mild fire separately.*

Spiny crayfish – expert estimates of local population response to fires of varying severity

Of the 32 spiny crayfish species included in the spatial analyses, expert elicitation on the population response to fire-related aquatic impacts of different severity were carried out for 25 species with the higher aquatic impact overlap values and those with a poor conservation status.

The expert judgements on the local population changes in the event of no, mild and severe fire or aquatic impacts, from just after the fire (one week), at one year post-fire, and 10 years/three generations post-fire, are summarised in Fig. 46. Species near the bottom of the left-hand panel are those that experts judged were most heavily impacted by severe fire-related aquatic impacts, experiencing immediate population losses of around 50%. Twelve species included in the elicitation have burrows connected to the waterway; these species may be more impacted by fire than species with burrows unconnected to waterways, as Fig. 46 suggests they are more likely to be positioned lower down in the graph (e.g. eight of the 12 are positioned in the bottom half of the graph).

The second panel, which summarises the local population changes at one year after fire, shows that the ordering of species in terms of relative fire impacts begins to rearrange. However, the size of population loss has generally increased, reaching over 60% in the most affected species, reflecting expert opinion that mortality rates in the year after fire are elevated for many species, partly because the aquatic impacts following fire can occur weeks or months after the fire event itself. By 10 years/three generations, species have re-ordered further. The relative differences between populations exposed to severe, mild and no fire impacts are still evident, but have diminished, especially for the several species exposed to mild fire impacts near the top of the graph, some of which may recover by that time. However, in no species were populations exposed to severe aquatic impacts fully recovered by 10 years/three generations.

Uncertainty about the local population response increased with increasing time since fire and was greater for the severe fire scenario that the mild and no fire scenarios (Fig. 46, and see section on Uncertainty overleaf).

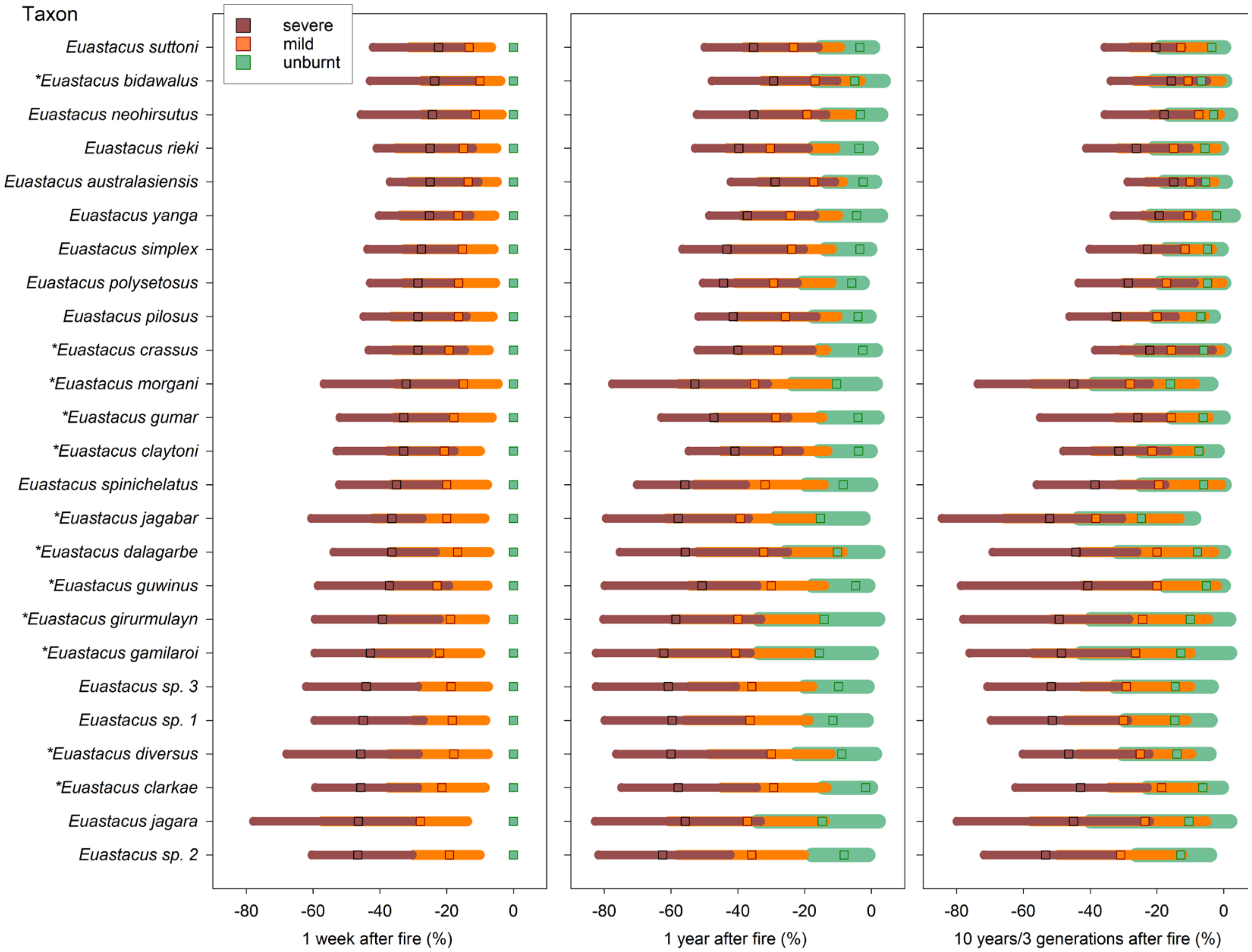


Fig. 46. *The expert judgements on the population changes at a site after severe and mild fire-related aquatic impacts, and no impacts (i.e. unburnt); from just before the fire, to 1 week, 1 year, then 10 years/three generations (whichever is longer) after the fire. Each bar shows the plausible estimate and the 80% confidence bounds, averaged across experts. Species with burrows connected to the stream are shown with an asterisk.*

Spiny crayfish – estimated overall population decline for each species

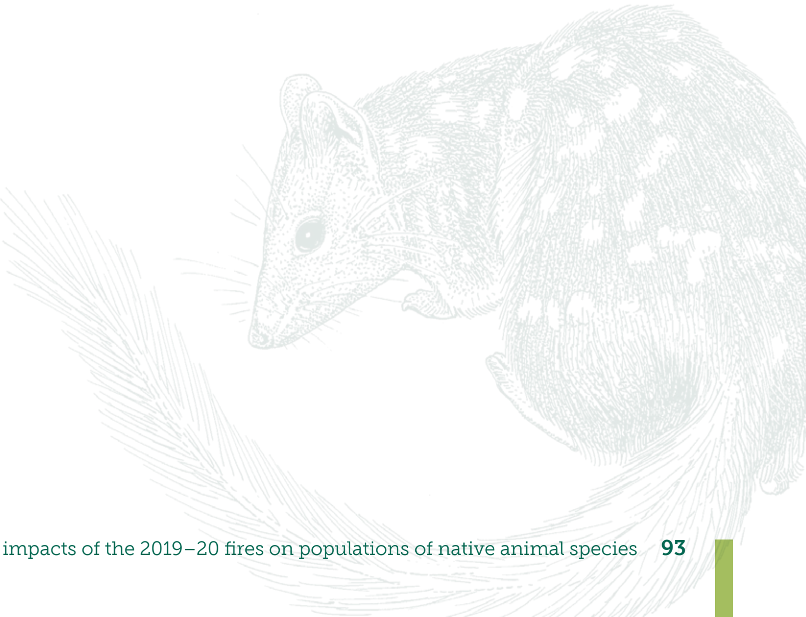
The expert estimates for proportional population change after fire impacts (above ground and aquatic) of varying severity, assuming conditions of current management, were combined with the estimates for the proportions of each species distribution affected by each fire impact class to derive estimates of the overall population change in each species. The effects of management, including enhanced management, on population change are explored in a companion report.

The estimates for the overall population change in these species, at three time points after fire, are shown in Fig. 47. The estimates for overall population decline immediately after the fire average to a 14% reduction across all 25 species for which elicitation was conducted; and range from zero for *Euastacus dalagarbe* (as the spatial analysis indicated the species distribution did not overlap with fire impacted areas) to a 44% reduction for *Euastacus clarkae*. By one year after fire, the population changes across all species averaged a 25% reduction, reflecting that in most species, the post-fire impacts including instream sedimentation events cause additional mortality; *Euastacus clarkae* was still the most adversely affected, with a 56% reduction in overall population size relative to before the fires. By ten years/three generations, the average overall decline was 20%, reflecting expert opinion that most species will show some recovery. By this time, the species with the worst population loss was *Euastacus* sp. 2, with a 46% reduction relative to its pre-fire population size. Inspection of the 80% confidence bounds suggest that seven species may be reduced by 50% one year post fire, and that six species may be reduced by at least 50% by 10 years/three generations post fire. In general, the confidence bounds of estimated population changes for each taxon increased with time after fire.

Only one species, *Euastacus neohirsutus* had bounds that included ‘0’ (i.e. potentially full recovery) by 10 years/three generations, and this taxon was only minimally affected by fire (mild fire impacts in 1% of its distribution). However, most taxa were predicted to have populations at 10 years/three generations that were larger than those at one year post-fire, even if they had not recovered fully to the pre-fire population size. Exceptions were *Euastacus morgani* and *Euastacus jagabar* (Figs. 47, 48).

Variation in post-fire trajectories among species could reflect the time required for critical resources to re-establish, difference in management inputs and their effectiveness, or that the taxon is experiencing ongoing decline due to other threats. To disentangle any legacy effects of fire-related aquatic impacts on the longer-term population trajectory, we compared the estimates for the overall population change after fire to the estimates for population change in the unburnt scenario, for each taxon (Fig. 47). The differences between the predicted population changes at 10 years/three generations, with and without the 2019–20 fires, are summarised across taxa in Fig. 48. The taxa with the largest population deficit (by almost 40%) as a result of the 2019–20 fires include some of those that experience fire impacts over a larger proportion of their distribution. For example, of the four species with highest fire impact overlap proportions, three are in the top 10 species with larger fire-related population deficits at 10 years/three generations.

If fire class 2 was grouped with unburnt, rather than with mild fire, the average population decline was reduced by 1.6%, 2.1% and 1.1% immediately, 1 year, and 10 years/three generations after fire respectively. These averages were calculated after excluding the species with burrows connected to waterways, as fire impacts for these species were estimated using the aquatic impacts spatial model. Only 1 species had an estimate for population decline that differed by more than 5% in any time period, depending on how fire class 2 was categorised: *Euastacus* sp. 3 had a decline one year after fire of 36% rather than 42% when fire class 2 was categorised as unburnt (Appendix 1f).



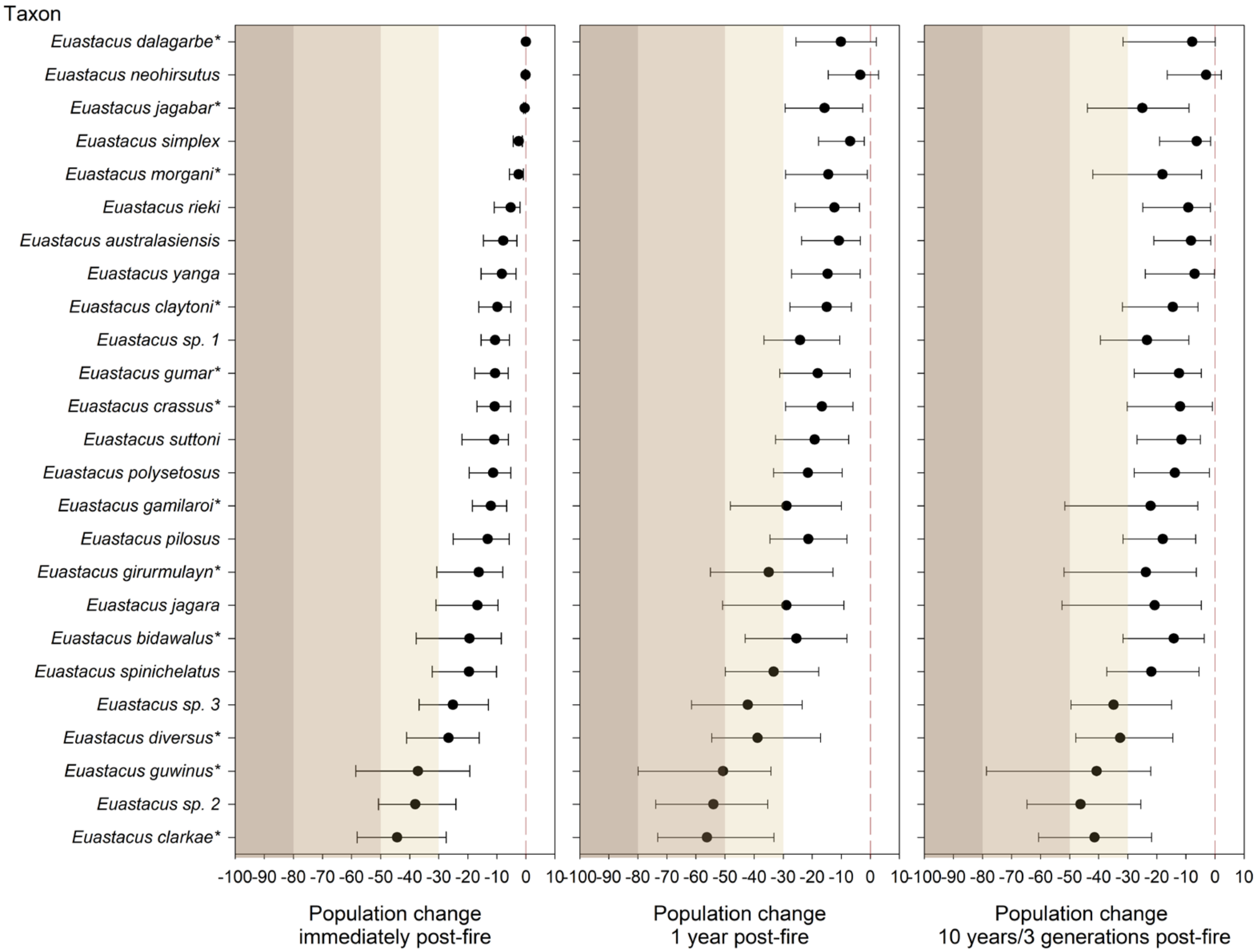
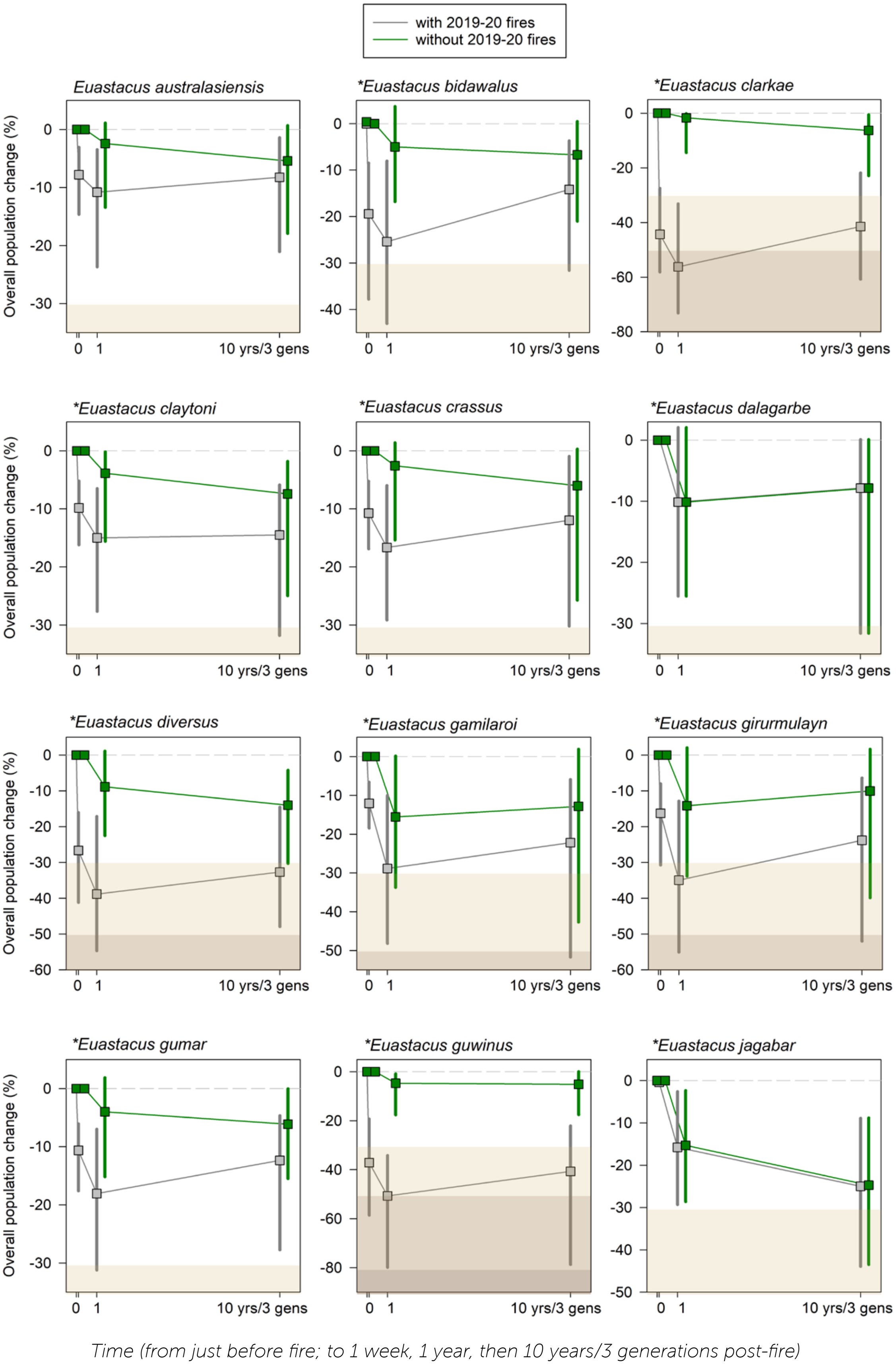
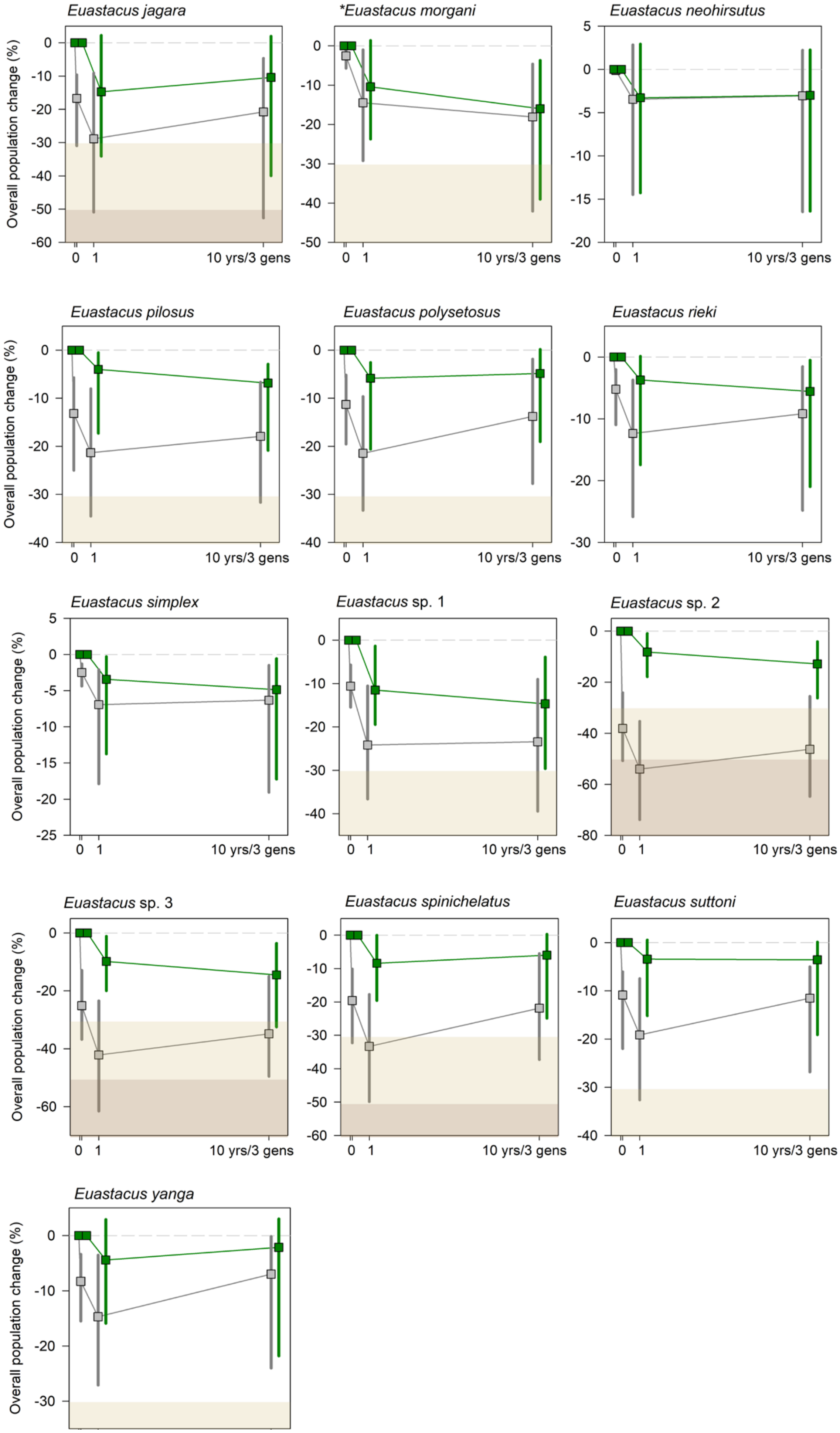


Fig. 47. *The overall population change in 25 spiny crayfish taxa, 1 week, 1 year and 10 years/three generations after the 2019–20 fires. Taxa are arranged in order of increasing population decline immediately after fire. The estimates are based on combining expert judgement on population response to fire impacts of different severity, with spatial analysis of the proportion of each taxon's range affected by severe and mild fire impacts. The graphs show the average estimates and 80% confidence bounds across the expert judgements. Species with burrows connected to waterways are shown with an asterisk. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%; dark brown is 80%).*

Fig. 48. (next 2 pages) *Changes in overall population size for each taxon, given the 2019–20 fires (grey lines), and if the fires had not occurred (green lines). Population changes are based on the expert judgements of how each taxon responds to fire impacts of varying severity, combined with the spatial analyses of the proportions of each taxon's range that overlapped with severe and mild fire impacts. Data represent the average estimate and 80% confidence bounds across experts. Both population responses assume no further large-scale fire within the 10 year/three generation period. Species are arranged alphabetically by scientific name, and those with burrows connected to waterways are shown with an asterisk. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%; dark brown is 80%).*





Time (from just before fire; to 1 week, 1 year, then 10 years/3 generations post-fire)

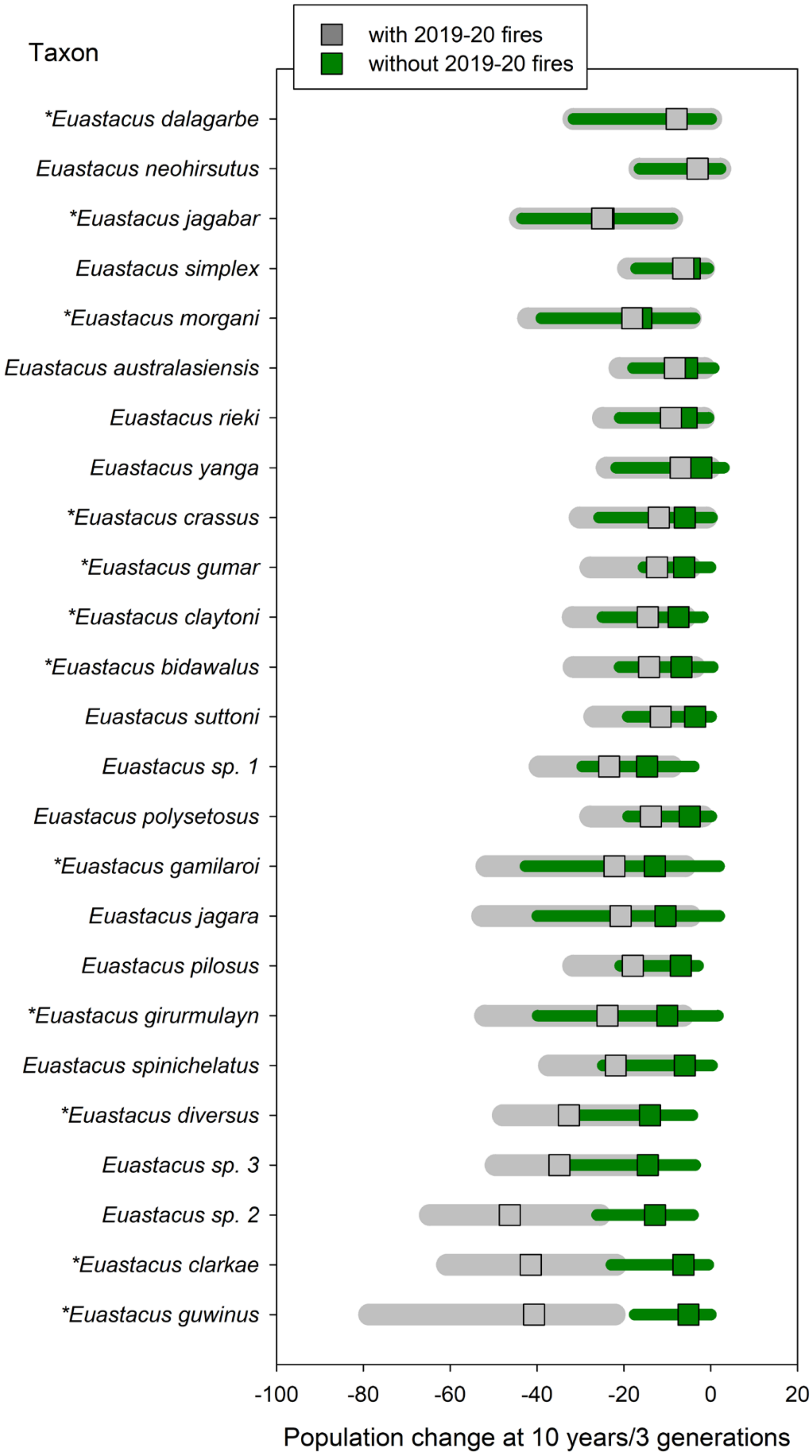


Fig. 49. The legacy effects of the 2019–20 fires, 10 years/three generations later. The graph shows the predicted population change, with 80% confidence bounds, for each taxon given the 2019–20 fires (grey), and if the fires had not occurred (green). Species are sorted on this graph by the magnitude of the legacy effects of fire: these are greater in taxa near the bottom of the graph, where the differences in predictions for overall population change between burnt and unburnt scenarios are greatest. Spiny crayfish species with burrows connected to the waterway are shown with an asterisk.

Spiny crayfish – priorities for conservation status review

Of the 32 spiny crayfish taxa considered in this assessment, 29 have fire-related aquatic impacts over more than 5% of their distribution, and have experienced overall population declines of varying magnitude as a result. We estimated the population loss using an expert elicitation procedure for 25 taxa. The elicitation indicated that all taxa will decline as an immediate result of fire, that the decline will worsen by one year post-fire, but that most taxa will show some recovery by 10 years/three generations after fire. These predictions assume no further extensive fire events, but climate modelling suggests periods of extreme fire weather will become increasingly common (Williams *et al.* 2009; Di Virgilio *et al.* 2019). Thus, the predictions are likely underestimates. Recurrent fires that occur before full recovery has occurred will gradually culminate in a downward population trajectory, especially if they cause permanent changes in stream architecture.

We reviewed the estimated population change immediately after fire, at one and 10 years (or three generations) for all taxa included in the expert elicitation, and their current conservation status under the EPBC Act, as well on the IUCN Red List. We focussed on the most plausible estimate and the lowest 80% confidence bound for the population loss, to develop the following guidelines:

- If the taxon is listed by IUCN as CR or EN, and has experienced fire-caused population loss, it is likely to be eligible for listing and we recommend the taxon be assessed.
- If the taxon is listed by IUCN as VU, and has experienced fire-caused population loss, it may be eligible for listing and we recommend the taxon be considered for assessment.
- If the taxon is not listed by IUCN, and the predicted estimates (average to lower bound) for population decline exceed 30%, it is likely to be eligible for listing and we recommend the taxon be assessed.

For taxa not included in the elicitation, we examined the proportion of the distribution affected by fire or aquatic impacts (Fig. 50). Based on the relationship between the proportion of a taxon's distribution affected by fire impacts and the extent of its population decline (Fig. 49), we suggest that if the distributional proportion is greater than 30%, listing assessment be considered.

Based on our guidelines, we suggest that 23-27 species of spiny crayfish could be eligible for listing under the EPBC Act (Fig. 51). This is a higher number of taxa than most vertebrate groups (with the exception of birds), and reflects both the susceptibility of spiny crayfish to bushfire-related impacts, as well as that the conservation status of spiny crayfish, and invertebrates more broadly, are poorly represented in the EPBC Act. The increasing future fire risk and the fact that another 24 spiny crayfish species that are not part of our assessment are classified as threatened (VU, EN, CR) under IUCN, make a whole-of-genus assessment for EPBC Act listing a priority.

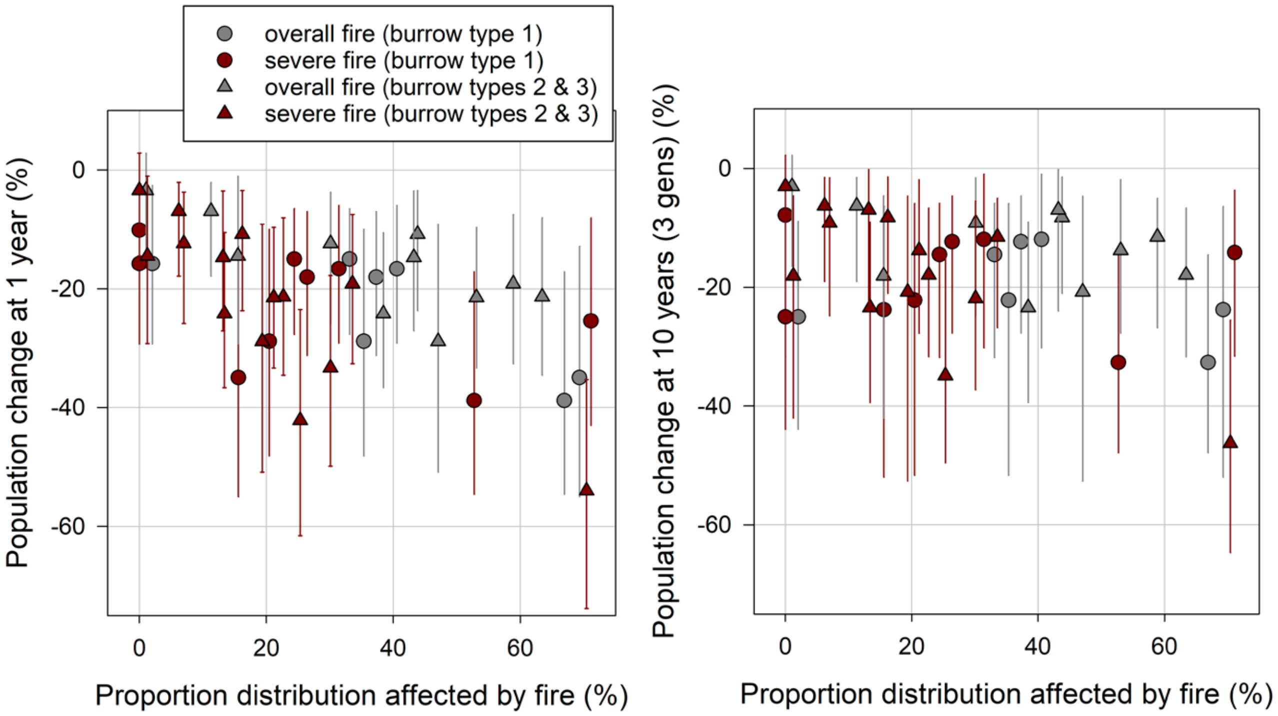
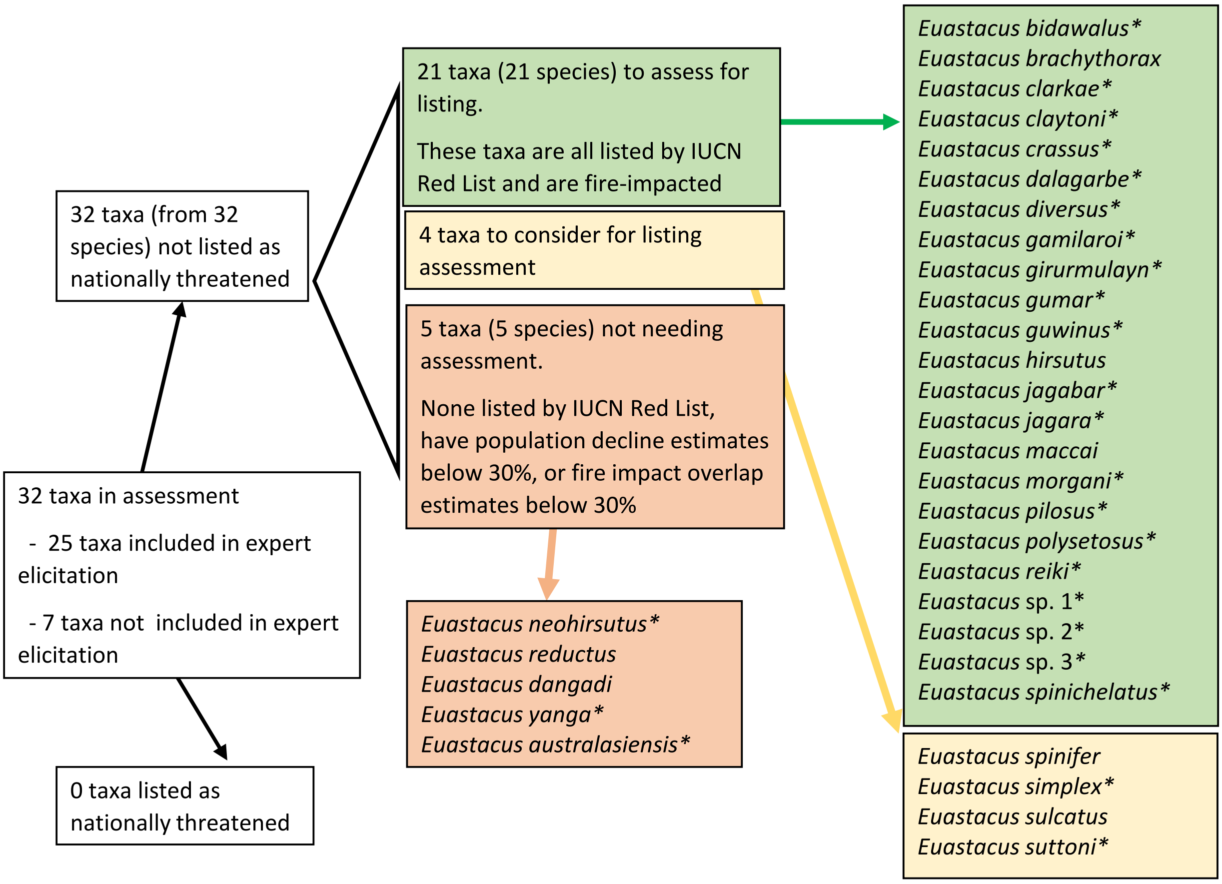


Fig. 50. *The population change, as estimated by experts, for 25 spiny crayfish taxa at 1 year (left), then at 10 years/3 generations (right) against the proportions of their distributions that overlapped with fire impacts (grey) and with severe fire impacts (brown).*



32 taxa in assessment

- 25 taxa included in expert elicitation
- 7 taxa not included in expert elicitation

0 taxa listed as nationally threatened

32 taxa (from 32 species) not listed as nationally threatened

21 taxa (21 species) to assess for listing.

These taxa are all listed by IUCN Red List and are fire-impacted

*Euastacus bidawalus**
Euastacus brachythorax
*Euastacus clarkae**
*Euastacus claytoni**
*Euastacus crassus**
*Euastacus dalagarbe**
*Euastacus diversus**
*Euastacus gamilaroi**
*Euastacus girurmulayn**
*Euastacus gumar**
*Euastacus guwinus**
Euastacus hirsutus
*Euastacus jagabar**
*Euastacus jagara**
Euastacus maccai
*Euastacus morgani**
*Euastacus pilosus**
*Euastacus polysetosus**
*Euastacus reiki**
Euastacus sp. 1*
Euastacus sp. 2*
Euastacus sp. 3*
*Euastacus spinichelatus**

4 taxa to consider for listing assessment

Euastacus spinifer
*Euastacus simplex**
Euastacus sulcatus
*Euastacus suttoni**

5 taxa (5 species) not needing assessment.

None listed by IUCN Red List, have population decline estimates below 30%, or fire impact overlap estimates below 30%

*Euastacus neohirsutus**
Euastacus reductus
Euastacus dangadi
*Euastacus yanga**
*Euastacus australasiensis**

Fig. 51. A summary of recommendations for conservation status assessments for spiny crayfish. Names of taxa that warrant conservation status review are shown in green boxes, and those for which assessment should be considered are in yellow boxes. Species included in the elicitation are noted with asterisks. The full list of taxa with reasons for our recommendations for conservation status is in Appendix 1f.

Euastacus crassus. *Image: Rob McCormack*

Comparison across taxonomic groups

In this section, we summarise some of the differences among taxonomic groups in fire impact overlaps, expert estimates of site-level response to fire, estimates for overall population declines and recovery post fire, and the implications for conservation status assessments.

Fire impacts on species distributions

Of the 288 taxa included in the spatial analyses of fire impacts, 198 had distributions that overlapped with the fire severity map or the aquatic impacts map by at least 25%; 76 taxa had distributions that were at least 50% fire-affected; and 16 taxa had distributions that were at least 80% fire-affected (Table 7a). Of the taxonomic groups, birds had the largest number of taxa with fire-affected distributions (considering those with at least 25% of the range burnt); this was driven by a large number of fire-affected bird subspecies endemic to Kangaroo Island. Fewer fish and spiny crayfish taxa had fire-affected distributions of at least 25%, but the proportion of fish and spiny crayfish taxa with very high distributional proportions for fire-effects (i.e. at least 50%, or at least 80%), was greater than for other taxonomic groups (Fig. 52).

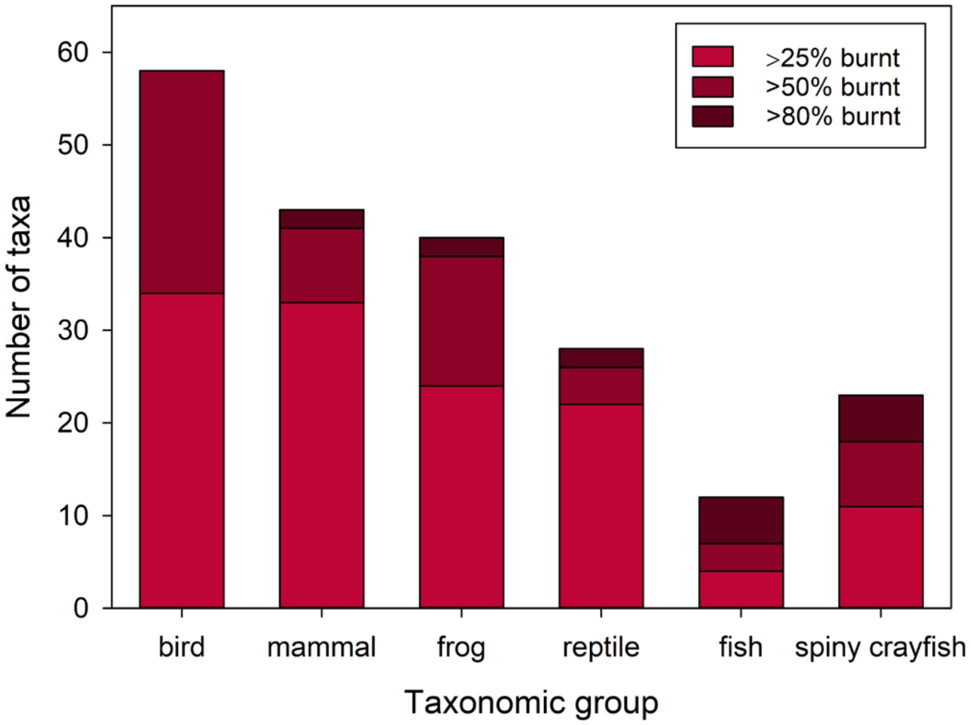


Fig. 52. *The numbers of taxa in each taxonomic group whose distributions were affected by fire, classed into at least 25% burnt, at least 50% burnt and at least 80% impacted (by fire or aquatic impacts).*

Of the taxa in our assessment, on average fish had the smallest distribution sizes, followed by spiny crayfish, and mammals the largest (Fig. 53). Taxa with smaller ranges were more vulnerable to having larger proportions of their distribution being fire-affected, although there was also greater variability in the fire overlap estimates for taxa with smaller ranges (Fig. 54).

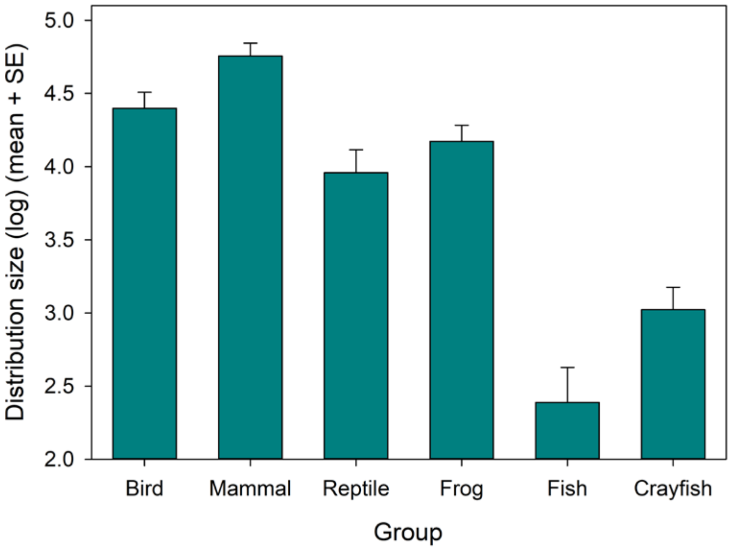


Fig. 53. Distribution (range) sizes of taxa in the assessment, for each animal group. Bars show means and standard errors of the logged range sizes.

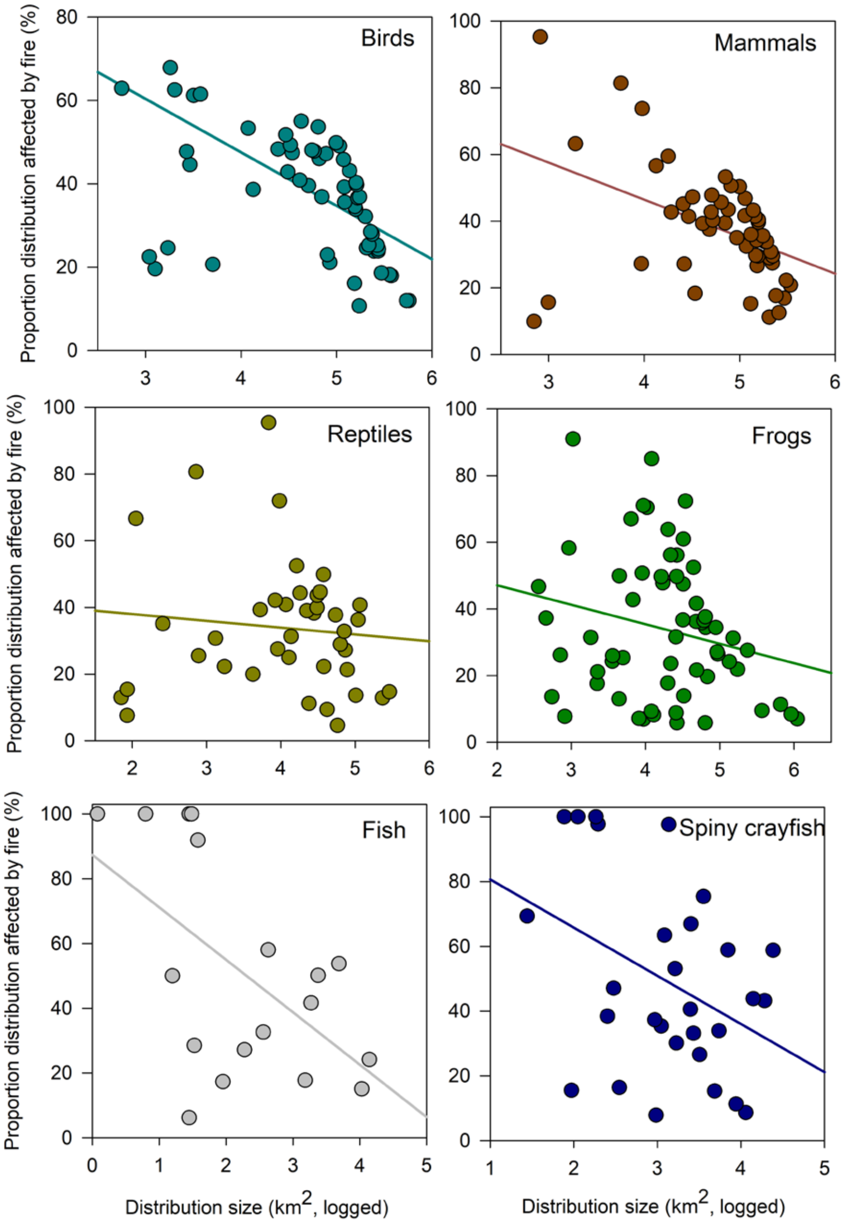


Fig. 54. The proportion of the distribution affected by fire against the distribution size (logged, km^2) for taxa in the six animal groups. Taxa with fire overlaps of less than 5% have been omitted.

Table 7. Summary of the number of taxa in the assessment across the main taxonomic groups, including the number in the spatial analysis, and the number in the expert elicitation, against extents of impacts, extents of recovery, and conservation status changes.

	Birds	Mammals	Frogs	Reptiles	Fish	Spiny crayfish
a) Spatial analysis of fire impacts						
Number of taxa (species) analysed	68 (54)	56 (46)	66 (47)	45 (40)	21 (21)	32 (32)
Number of analysed taxa (species) with 25% or more of distribution burned (bird seasonal migrants only counted once)	55 (45)	43 (36)	38 (30)	28 (26)	13 (13)	23 (23)
Number of analysed taxa (species) with 50% or more of distribution impacted	24 (22)	10 (8)	16 (14)	6 (6)	9 (9)	12 (12)
Number of analysed taxa (species) with 80% or more of distribution impacted	0	2 (2)	2 (2)	2 (2)	5 (5)	5 (5)
(b) Elicitation and overall population decline						
Number of taxa in elicitation (species)	28 (19)	43 (34)	31 (22)	30 (27)	16 (16)	25 (25)
Taxa with most plausible estimates of overall population decline at one week or one year post-fire of 25% or more	14 (10)	10 (8)	2 (2)	2 (2)	7 (7)	10 (10)
Taxa whose population increases between one week and one year post-fire	0; 0%	0; 0%	1; 3%	9; 20%	0; 0%	0; 0%
Taxa whose population increases between one year and 10 years/3 generations post-fire	18; 64%	18; 42%	8; 26%	16; 53%	1; 6%	25; 92%
Taxa where population recovery by 10 years/3 generations is **Likely** (mean estimate within 5% of pre-fire size)	4; 14%	0; 0%	4; 13%	11; 37%	0; 0%	1; 4% (1)
Taxa where population recovery by 10 years/3 generations is **Plausible** (80% confidence includes pre-fire size)	20; 71%	16; 37%	14; 45%	25; 83%	3; 19%	1; 4%
(c) Conservation status review						
Taxa (species) potentially eligible for listing	20-24 (18-22)	1-5 (1-5)	7-14 (7-14)	5-9 (5-9)	10-12 (10-12)	23-27
Taxa (species) potentially eligible for uplisting	1 (1)	9-13 (5-9)	11-12 (7-8)	1-5 (1-5)	1-3 (1-3)	0; none listed
Currently listed taxa (species) that are fire-impacted but probably not eligible for uplisting	8 (4)	8 (8)	6 (4)	2 (2)	5 (1)	0; none listed
Fire-impacted species already listed as CR	2	0	3	2	1	0

Expert estimates of local population response to fire

We carried out a structured expert elicitation to predict the local population response of 173 taxa across the six taxonomic groups, when they were exposed to mild or severe fire (or aquatic impact risk), or to no fire (or aquatic impact risk) (Table 7b). Experts predicted the population sizes just after the fire, one year later, then 10 years/three generations later (whichever is longer) for each taxon. The species with the largest predicted decline when exposed to severe fire was the Greater Glider, with an immediate local population loss of 85% (80% confidence range: 69% to 94%). The next most impacted taxon was the Kangaroo Island Southern Emu-wren, with an estimated population loss of 83% (confidence range: 76% -to 88%). Of the top 20 species with the largest local population losses immediately after fire, 14 were mammals, five were birds, and one was a reptile (Table 8a). The frog species with the greatest estimated local population loss, *Pseudophryne corroboree*, ranked 60th against all 173 taxa in the elicitation; the top spiny crayfish (*Euastacus* sp. 2) ranked 79th, and the top fish, *Galaxias rostratus*, ranked 88th, with an estimated population loss of 43% (80% confidence range: 21% to 68%) immediately after fire (Appendix 1g).

By one year after fire, the ordering of taxa had shifted somewhat: nine mammal species and 11 bird species comprised the top 20, and *Cyclodomorphus praealtus* had dropped to 44th rank. *Euastacus* sp. 2 ranked 63rd, the top-ranked fish, *Galaxias* sp. nov. 'yalmy', was 68th, and *Litoria watsoni* was now the top-ranked frog at 76th (Appendix 1g).

By 10 years/three generations after fire, the top 20 species in terms of their estimated local population loss after being exposed to severe fire comprised nine mammal species, five frog, four fish, two bird, but no reptile or spiny crayfish species (Table 8b). The rearrangement of taxa from one week, to 10 years/three generations after fire reflects variation among species in their recovery trajectories post-fire.

Taken together, the results suggest that of the taxa included in this elicitation, mammals and birds experience the greatest immediate impacts from severe fire, at least out to one year after fire. By 10 years/three generations after fire, mammals are still the most heavily impacted relative to other groups, birds were predicted to show more recovery, but frogs and fish either fail to recover, or continue to decline because of the effects of other threats. Reptiles and spiny crayfish are generally less impacted at a local scale by fire, and recover better after fire, than mammals and birds, but with notable exceptions, including the turtles (*Wollumbinia* spp.), and *Eulamprus leurensis*, all of which are declining strongly as a result of other threats.

*Regent honeyeater (*Anthochaera phrygia*). Image: Derek Keats CC BY 2.0 Wikimedia Commons*

Table 8. The 20 species predicted to experience the greatest site-level population losses (a) in the week after fire; and (b) by 10 years/three generations after fire. For each species, the table shows the most plausible estimates for the population loss and the 80% confidence bounds.

Group	Name	Species	Most plausible population loss (%)	Lower plausible	Upper plausible
(a) One week after severe fire					
Mammal	Greater Glider	*Petauroides volans*	85.4	93.5	69.1
Bird	KI Southern Emu-wren	*Stipiturus malachurus halmaturinus*	83.2	88.1	76.4
Mammal	Yellow-bellied Glider	*Petaurus australis* (SE Australia)	81.7	90.4	67.7
Mammal	Swamp Rat	*Rattus lutreolus*	80.7	91.3	68.0
Mammal	Silver-headed Antechinus	*Antechinus argentus*	80.3	88.3	69.2
Mammal	Mainland Dusky Antechinus	*Antechinus mimetes*	79.4	82.8	72.1
Mammal	Koala	*Phascolarctos cinereus*	76.5	86.2	60.6
Bird	Yellow-throated Scrubwren	*Sericornis citreogularis citreogularis*	75.1	83.2	58.7
Mammal	Agile Antechinus	*Antechinus agilis*	74.6	83.3	61.4
Mammal	Brown Antechinus	*Antechinus stuartii*	74.6	83.2	61.6
Bird	Red-browed Treecreeper	*Climacteris erythrops*	73.5	83.1	62.9
Mammal	Long-footed Potoroo	*Potorous longipes*	72.3	79.4	56.9
Bird	Albert's Lyrebird	*Menura alberti*	71.8	80.3	60.5
Bird	Western Ground parrot	*Pezoporus wallicus flaviventris*	71.4	74.1	62.9
Reptile	Alpine She-oak Skink	*Cyclodomorphus praealtus*	71.3	89.3	33.7
Mammal	Hastings River Mouse	*Pseudomys oralis*	70.4	87.4	50.7
Mammal	Broad-toothed Rat	*Mastacomys fuscus mordicus*	70.3	83.5	57.3
Mammal	Golden-tipped Bat	*Phoniscus papuensis*	70.1	88.0	42.6
Mammal	KI Dunnart	*Sminthopsis fuliginosus aitkeni*	70.0	82.7	53.0
Mammal	Sugar Glider	*Petaurus breviceps* (newly classified)	69.9	83.3	48.3
(b) 10 years/three generations after severe fire					
Mammal	Greater Glider	*Petauroides volans*	86.4	93.4	64.3
Mammal	Yellow-bellied Glider	*Petaurus australis* (SE Australia)	78.1	91.0	62.6
Mammal	Silver-headed Antechinus	*Antechinus argentus*	67.1	87.2	47.4
Mammal	Mainland Dusky Antechinus	*Antechinus mimetes*	65.3	81.6	42.0
Mammal	Long-nosed Potoroo	*Potorous tridactylus*	64.9	82.4	39.6
Fish	Yalmy Galaxias	*Galaxias* sp. nov. 'yalmy'	64.3	94.6	42.2
Frog	Mountain Frog	*Philoria kundagungan*	64.3	85.9	32.8
Frog	Richmond Range Sphagnum Frog	*Philoria richmondensis*	64.3	85.9	32.8
Bird	Rufous Scrub-bird	*Atrichornis rufescens*	64.1	90.9	33.6
Mammal	Smoky Mouse	*Pseudomys fumeus*	63.1	81.3	42.0
Bird	Western Ground Parrot	*Pezoporus wallicus flaviventris*	63.0	89.3	25.4
Frog	Northern Corroboree Frog	*Pseudophryne pengilleyi*	62.8	88.0	44.1
Mammal	Koala	*Phascolarctos cinereus*	62.5	90.1	44.5

Group	Name	Species	Most plausible population loss (%)	Lower plausible	Upper plausible
Fish	Cann Galaxias	*Galaxias* sp. 17 'Cann'	61.4	96.4	41.6
Fish	Dargo Galaxias	*Galaxias mungadhan*	61.4	94.8	41.0
Fish	McDowall's Galaxias	*Galaxias mcdowalli*	61.4	92.9	42.0
Frog	Spotted Tree Frog	*Litoria spenceri*	61.3	92.3	22.5
Frog	Southern Corroboree Frog	*Pseudophryne corroboree*	61.1	88.0	41.2
Mammal	Broad-toothed Rat	*Mastacomys fuscus mordicus*	61.0	81.1	38.1
Mammal	Long-footed Potoroo	*Potorous longipes*	60.7	83.4	37.8

Overall population declines and recovery

The predictions about population responses to fires gained from the structured elicitation were combined with the results of the spatial analyses of the distributional overlaps with fire and aquatic impacts to produce estimates of overall population decline for 173 taxa.

Forty-five taxa had estimates for population decline at either one week or one year, that were at least 25% (based on the most plausible estimate from the elicitation). Birds comprised the largest number of taxa with population declines of 25% or more, followed by spiny crayfish and mammals, then fish, then frogs and reptiles having only two taxa each with overall population declines or 25% or more (Fig. 55; Appendix 1h). Note the balance of representation from the taxonomic groups in this summary of overall population decline differs from the balance generated by the elicitation (which was dominated by mammals; Table 8a), because the overall population decline integrates the elicitation results with the fire-distribution overlaps. By 10 years/three generations, only one of the 45 taxa with the greatest overall population decline was predicted to recover (the KI Glossy Black-Cockatoo, *Calyptorhynchus lathami halmaturinus*), but another nine taxa have confidence bounds that suggest recovery is plausible (i.e. the bounds overlap with zero; Fig. 55).

Taxa with the greatest overall population losses at 10 years/three generations were not necessarily the same taxa that had the greatest losses at one week, or one year after fire: of the 51 taxa with overall population declines exceeding 25% at 10 years/three generations, only 18 were part of the 45 taxa with the greatest overall population losses at one week or one year post fire. This is because by 10 years/three generations, the impacts of the 2019–20 fires are mixed with the ongoing effects of other threats. The 51 taxa comprised 14 fish, 12 mammal, eight frog, seven bird, six spiny crayfish and four reptile species (Fig. 56). The top six species with the worst population predictions 10 years/ three generations hence were all fish.

*Hasting river mouse (*Pseudomys oralis*). Image: Doug Beckers, CC BY-SA 2.0, Flickr*

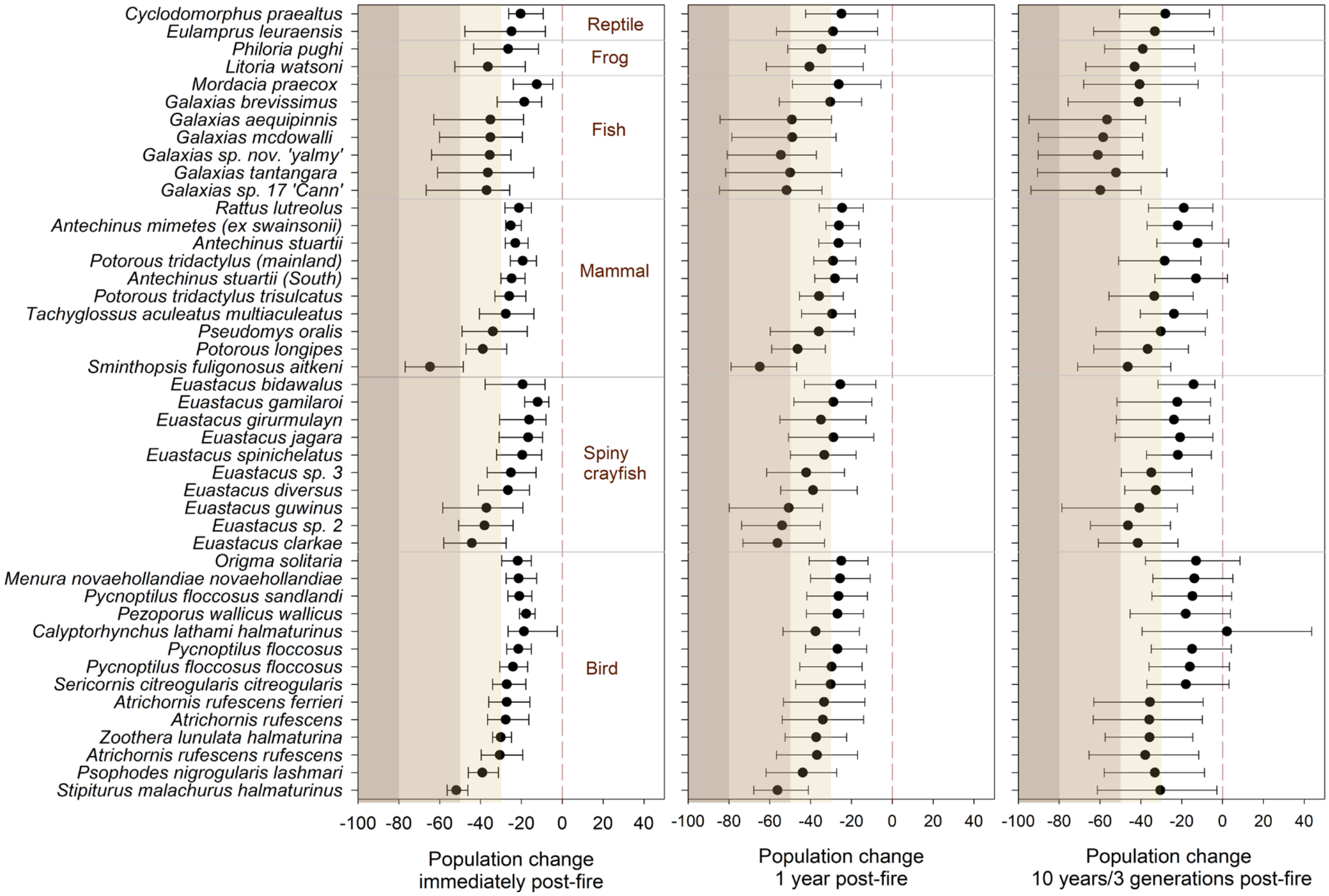


Fig. 55. *Summary of the overall population losses at 1 week, 1 year, and 10 years/three generations after fire, for all taxa in the elicitation predicted to experience declines of at least 25% either one week, or one year, after fire. Taxa are arranged by taxonomic group, and then by the extent of population decline at one week post fire. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%; dark brown is 80%).*

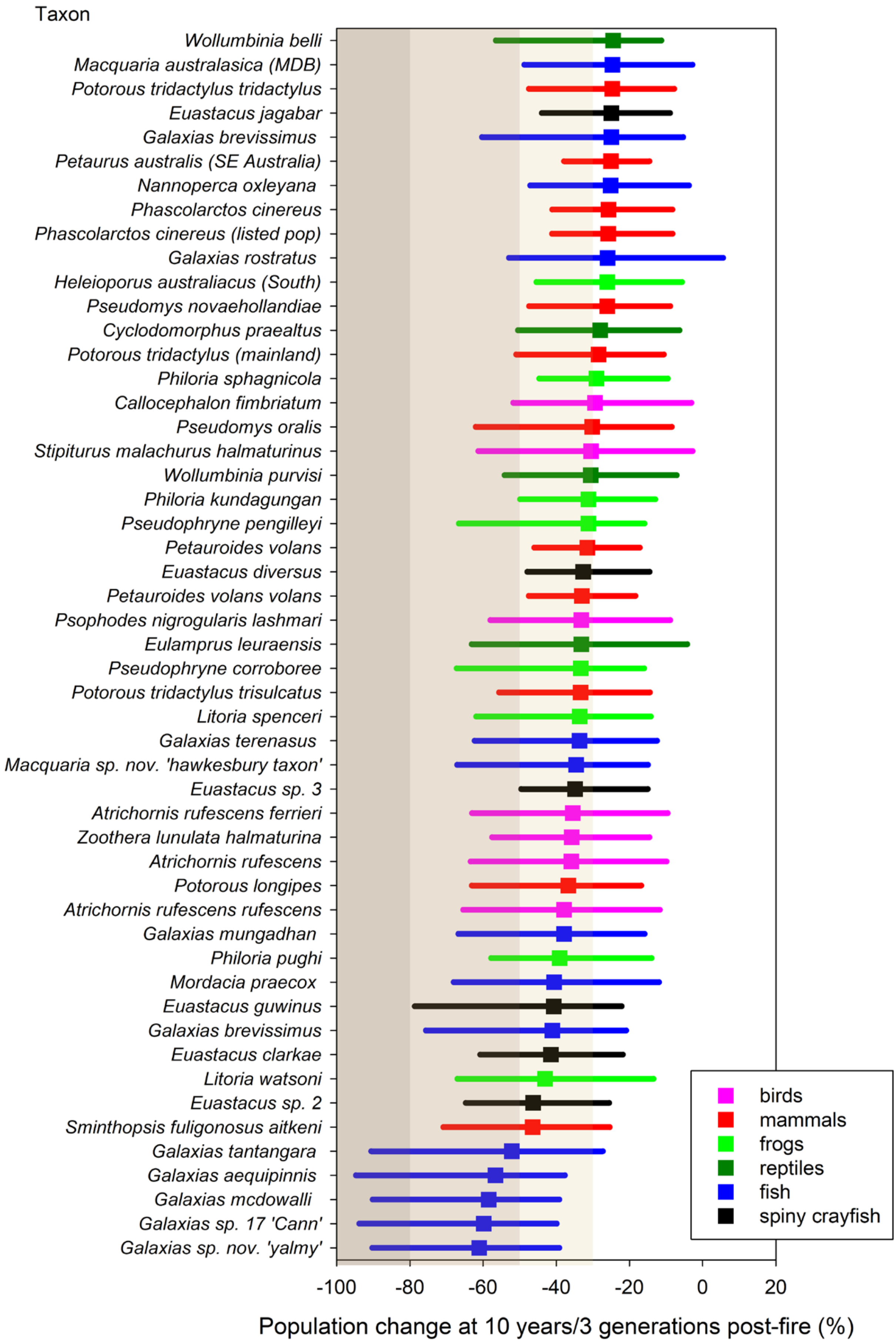


Fig. 56. *Overall population losses at 10 years/three generations, for the 50 taxa with predicted declines of at least 25%. The graph shows the estimate for the most plausible population change and the 80% confidence bounds around that estimate. Background shading indicates population decline thresholds for listing categories under Criterion A of the IUCN Red List Guidelines (light brown is 30%; mid brown is 50%; dark brown is 80%).*

Population recovery

Most taxa declined between one week and one year after fire, reflecting expert opinion that mortality rate is elevated in the post-fire environment (Table 7b). Reptiles were most likely to be exceptions to this pattern, with 20% of taxa increasing over this period. Between one year and 10 years/three generations, expected population recovery varied across the taxonomic groups, from only 6% in fish to 92% of spiny crayfish taxa (Table 7b). Population recovery back to pre-fire levels was plausible (i.e. the 80% confidence range included the pre-fire population size) for 79 of the 173 taxa involved in the elicitation, and likely (i.e. the most plausible population estimate was within 5% of the pre-fire population size) for only 19 of the 173 taxa (Fig. 57; Table 7b). Reptiles were the group with the largest proportion of species that were predicted to plausibly recover (87%), followed by birds (71%), frogs (45%) and mammals (37%), whereas fish and spiny crayfish had the lowest proportion of taxa predicted to plausibly recover (19%, 4% respectively; Fig. 57, Table 7b). These predictions were all based on the assumption that current management settings continued into the future and that there were no further severe fires or droughts.

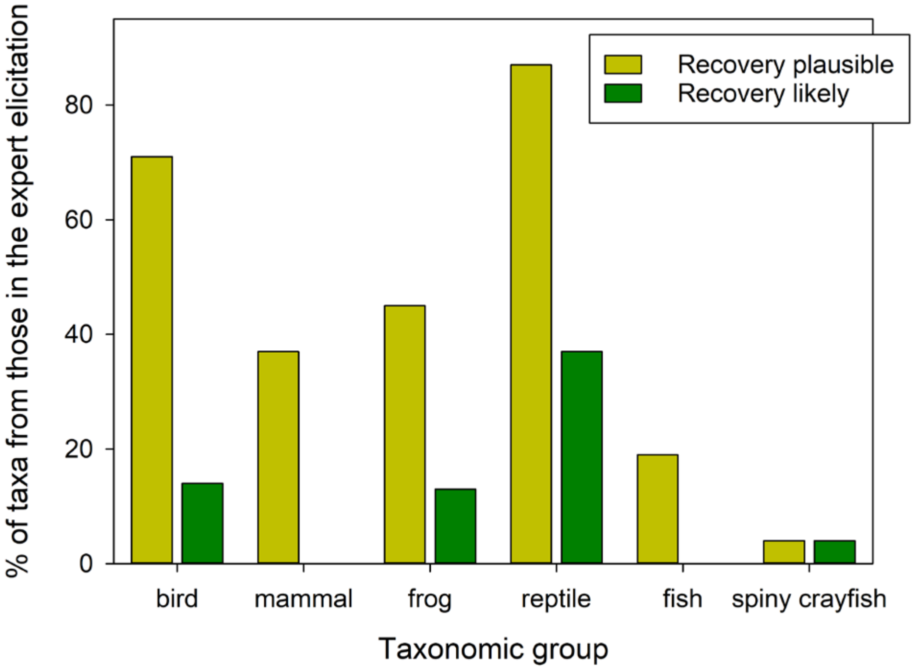


Fig. 57. The proportions of taxa in each taxonomic group that could plausibly recover, or that are likely to recover, back to their pre-fire population sizes, by 10 years/three generations after the 2019–20 fires.

Conservation status review

Based on the estimates for predicted population declines, and information about the pre-fire population status and trends summarised in the EPBC Act lists, the IUCN Red List, relevant Action Plans and other expert assessments, we suggest that 66-91 taxa may be eligible for listing under the EPBC Act as a result of the 2019–20 fires, in some cases compounding declines that had not yet been recognised under national legislation (Table 7c). Twenty-three to 34 taxa that are already listed under the EPBC Act may now be eligible for uplisting, subsequent to the 2019–20 fires. In addition, the status of another 37 listed taxa has worsened as a result of the 2019–20 fires, including eight taxa listed as CR (Table 7c).

We stress that our evidence does not comprise a conservation status review for each taxon in the assessment, but rather our assessment contributes one line of evidence that could be used in such a review. Ultimately, on-ground surveys and long-term monitoring to describe the status and trends of populations, their exposure to threats, and their response to management, are needed to inform conservation assessments and recovery planning.

Interpreting uncertainty

Each expert judgement on the proportional population changes after fire included upper and lower bounds around their most plausible estimate, and a measure of their confidence that the true value lay within those bounds. For the assessment, we then standardised the confidence bounds of each judgement to 80%. In the sections above covering each taxonomic group, we considered the 80% confidence bounds as well as the most plausible population estimates when reviewing conservation status, and when assessing whether taxa were likely to recover after fire by 10 years/three generations. Here, we summarise patterns of uncertainty across taxonomic groups, across fire scenarios, and over time (Fig. 58). Note that 'severe fire' refers also to severe aquatic impacts; 'mild fire' refers also to mild aquatic impacts. Key patterns include:

- Across all taxonomic groups, expert's uncertainty around the most plausible estimates increased with longer time periods after fire; this is expected, as predictions of population change further into the future are more challenging.
- In all taxonomic groups, uncertainty was generally greatest for the severe fire scenario, and lowest for the no fire scenario. This indicates that field survey data are required to improve our knowledge of what happens to populations after fire, and especially after severe fire.
- Immediately after severe fire, the median uncertainty was least for birds and greatest for reptiles, then frogs and fish, indicating that post-fire surveys in reptiles, frogs and fish groups would be especially valuable for improving predictions of immediate population response to severe fire.
- Immediately after mild fire the differences among taxonomic groups was more muted.
- In the no fire scenario, uncertainty was more variable across frog experts than for experts in other groups, possibly reflecting diverging opinions about the future population prospects for frog species in the assessment.The greatest median uncertainty at 10 years/three generations was attached to fish species, followed by bird species.

In a companion report, we explore patterns of uncertainty in population response further, including in contrasts of different management options.

Heleioporus australiacus. *Image: Chris Jolly*

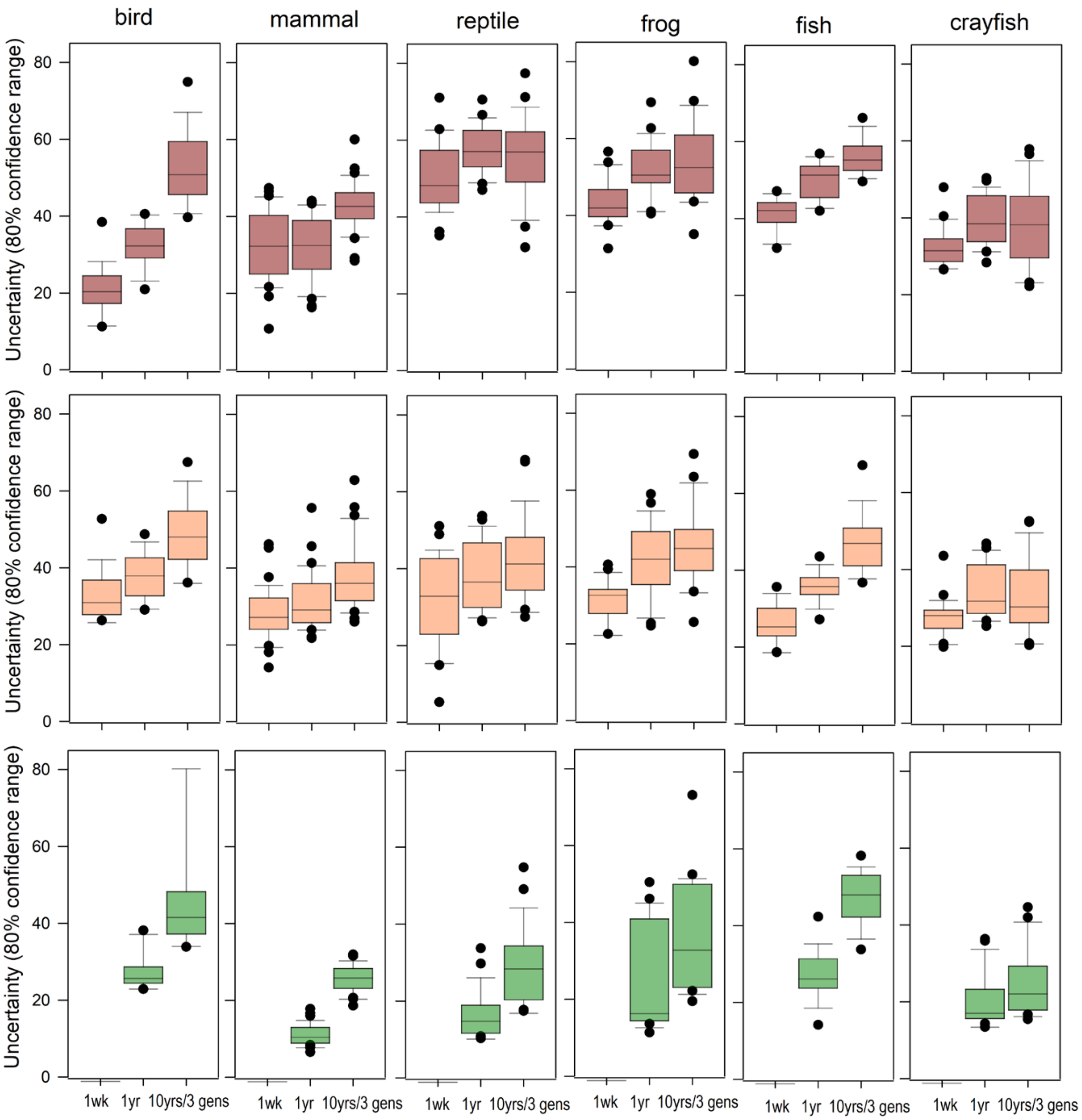


Fig. 58. *Uncertainty in the population estimates at three time periods after fire, for each taxonomic group, in the severe fire/aquatic scenario (top panel), the mild fire/aquatic scenario (middle panel); and the no fire scenario (lower panel). Box plots show the media, 10th, 25th, 75th, 90th percentiles of the uncertainty range (the difference between the upper and lower 80% confidence bounds). Higher values therefore indicate greater uncertainty.*

Lessons from the study

The estimates for population loss and recovery presented here are based on combining expert judgement on species response to fire, with spatial analyses of the intersects between species distributions and fire severity mapping (or aquatic impact severity mapping). There are several sources of imprecision, and some of these highlight priorities for future improvements in data acquisition and access.

The GEEBAM **fire severity** dataset was designed as an interim product, and had little ground truthing. Although the mapping was optimised to vegetation type and bioregions, local spatial variation in vegetation structure and terrain are difficult to accommodate in a national-scaled mapping tool. Fire impacts may have been overestimated in some areas, and underestimated in others. Fine-scale mosaics of burnt and unburnt patches may have been unmapped. Some topographical features, such as steep gullies, show as a relatively small area compared with exposed ridges when modelled in two dimensions, but could represent a significant refuge for fauna. Nevertheless, the GEEBAM product was the first national fire severity map, and an important tool for undertaking national scale analyses of impact.

- Given the increasing frequency of large fires extending across jurisdictional borders, a facility for rapidly assembling and displaying data on fire extent and severity, as well as other fire-related information, would be valuable.

Taxonomic uncertainty (especially in frogs and reptiles) clouds assessments of fire impacts. We incorporated likely taxonomic updates where possible (Catullo and Moritz 2020) and carried out spatial analyses of fire overlaps on candidate species and subspecies, but sometimes the distributional limits of these taxa are still unresolved.

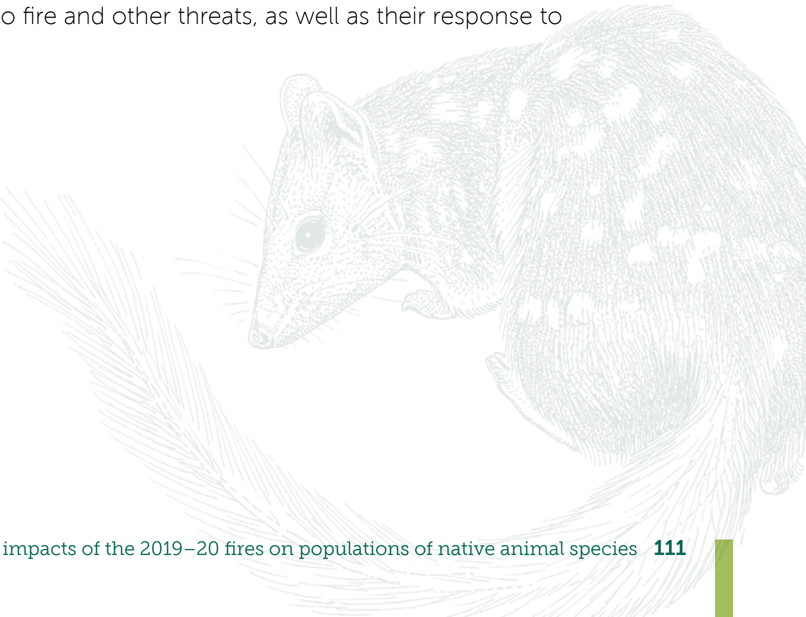
- Taxonomic information underpins all aspects of conservation, and efforts to improve the quality and consistency of taxonomic information are needed.

Distribution information for many taxa is limited and/or biased, for example with observations clustered in more accessible locations, or with few recent observations which is a particular problem for species experiencing recent population declines. Although we tried to account for this using a bias correction step in the species distribution models, these issues hamper the quality of estimates of overlap with fire impacts, with potentially large errors possible for taxa with very small distributions. Distribution data are also difficult to source – data are held across multiple institutions, each with idiosyncratic data sharing agreements, that make collating and managing distribution data onerous. Further, for most taxa, we lack any field data on spatial variation in density, so our spatial analyses used 'flat' range maps; our estimates of proportional fire impacts would be much enhanced if we had information about density variation across the ranges of taxa, because severe fire in locations of high animal density will have a far greater impact than a mild fire in locations where animal density is low. This is an important field of research, not only for fire effects, but for also for other impacts, such as drought and logging, as well as for the selection of protected areas.

The **conservation status** of many taxa under the EPBC Act is out-of-date or misaligned, especially for groups like fish and spiny crayfish, making judgements about their pre-fire conservation security, the degree to which they are affected by threats, and how responsive they are to management intervention, challenging.

For most taxa, we lack any **field data on population response to fire**, especially to fires of the scale and severity witnessed in 2019–20. In our assessment, we used expert elicitation to fill this data gap, but much more field data are required.

- A national facility to collate, curate and store fundamental data on species genetic diversity, distributions, status and trends would support many functions, including coordinated responses to future large-scale disturbance events (fire, drought, flood, etc), and timely reviews of conservation status across taxa.
- Substantially enhanced research, survey and monitoring effort is needed to track changes in the distribution and status of taxa, and to understand their response to fire and other threats, as well as their response to management inputs.



Future work

Our overall study had three aims. This report addresses the first of those aims:

- Improve estimates of the impacts of the 2019–20 bushfires on native vertebrate species and spiny crayfish species, and describe the likely trajectories for population recovery across species.

Subsequent reports will build on the present assessment, and seek to address the second and third aims of the study:

- Improve our understanding of the species' traits that affect susceptibility to fire events and their capacity to recover, to inform response to future such events.

  We will explore whether and how a range of behavioural, ecological and life history traits relate to the expert estimates of site-level responses to fires of different severity.

- Understand the extent to which current management is supporting the recovery of species, and where extra investment is needed to ensure that recovery.

  The expert judgements used in this report were based on the assumption that current management settings continued into the future. However, experts also provided judgements on the population response to fire in the event of no management, and of ideal management, for each taxon. The dividend of current management inputs, and the potential to boost those dividends with additional management, can be explored by looking at the expert judgements of population change across the management scenarios.

There are several more options for building on the work presented here, including:

1. Predicting longer-term population trajectories given a range of future climate scenarios. The expert judgements presented in this report were based on the assumption that the extreme drought that led to the 2019–20 fire season would not recur within 10 years/three generations. However, the frequency of such events is predicted to increase as the climate shifts, and longer-lived taxa in our assessment are highly likely to experience similar large-scale fire events within the assessment period. By embedding the expert-based population trajectories into more realistic increasing fire frequency scenarios, we could explore the longer-term conservation prospects for taxa affected by the 2019–20 fires.
2. Improving estimates of the scale and locations of impact by adding information about spatial variation in density, and also adding information about spatial variation in population genetics, for those taxa where such data are available.
3. Using the spatial analyses of fire impacts with species' distributions to identify priority sites for long term monitoring across multiple taxa, and using the estimates for population recovery rates to inform optimisation of the sampling design. Similarly, the information can be used to prioritise locations for investment in recovery actions.
4. We created a spatial model to estimate the areal extent and severity of fire-related aquatic impacts, by adapting pre-existing soil erosion models with the addition of spatially-explicit fire severity and rainfall data. The model appears to perform well against on-ground records of aquatic impacts, but further work to refine the aquatic impacts model (and define the spatial extent of downstream impacts) would be useful.
5. Undertaking post-fire surveys to verify/calibrate the results from this elicitation would not only inform conservation management, but also help refine the approach of using experts for this type of assessment. In addition, research to understand the longer-term fate of individuals from large-bodied species that are able to escape the immediate impacts of fire fronts would be valuable.

Data location

Summaries of fire severity and aquatic impact overlaps, expert judgements of site-level population responses to fire, and overall population declines are in Appendix 1 (https://www.nespthreatenedspecies.edu.au/media/nxsbaaf2/8-3-2_appendix1_final_20210811.xlsx)

Contact Sarah Legge or Darren Southwell for access to datasets on collated expert judgements, and species distributions.

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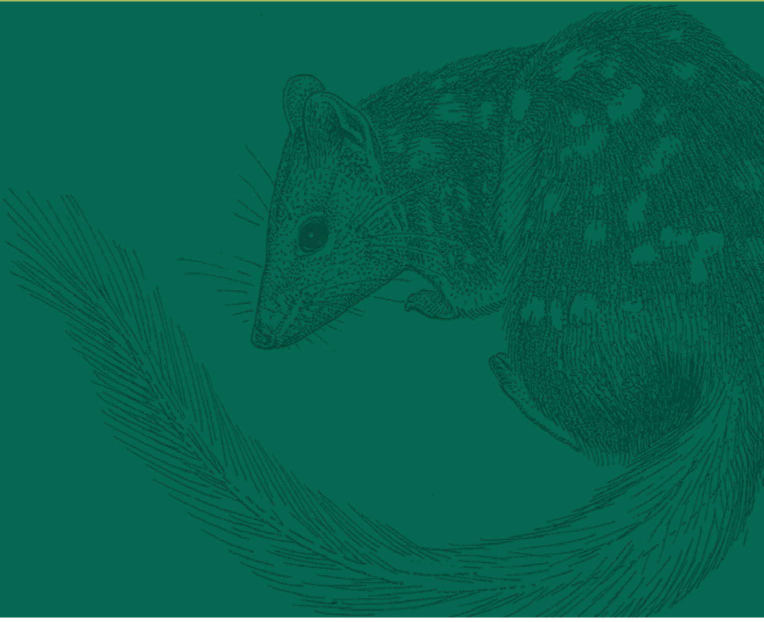

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