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The impact of the 2019–20 Australian wildfires on aquatic systems

Nick S. Whiterod, Mark Lintermans, Rebecca L. Cramp, Craig E. Franklin, Mark J. Kennard, Rob McCormack, Luke Pearce, Tarmo A. Raadik, Michelle Ward and Sylvia Zukowski

Summary

Context and challenges

- Wildfires pose profound, but often underappreciated, threats to aquatic ecosystems and species.
- The complex and dynamic impacts are predominantly realised with run-off events that operate at greater temporal (i.e. months to years) and spatial (i.e. tens of kilometres) scale than that imposed by the wildfire footprint.
- Freshwater fish and spiny crayfish (and other aquatic species) are typically understudied and receive little management attention, hindering the ability to understand impacts and recovery.

Main findings

- The studies summarised in this chapter reveal mortality of individuals (tens to thousands) from at least 32 aquatic species, with these impacts as far as 70 km downstream of fire-affected areas
- Spatial analyses predicted that fire-related impacts overlapped substantially with the distributions of 21 freshwater fish species and 21 spiny crayfish species; the entire known range of nine species was estimated to be affected.
- The population status of impacted species was often predicted to be worse 1-year post-fire than 1-week post-fire, because fire impacts can occur well after the fire event.
- For many species, recovery over 10 years or three generations was predicted to be slow, depending on pre-fire status and intrinsic traits of species.
- Emergency conservation efforts were initiated for at least 24 aquatic species across three jurisdictions and involved rescue, *ex situ* captive maintenance and later return to wild.

- Actions initiated and knowledge gained in response to the 2019–20 wildfires helped alleviate some impacts; future actions should attempt to build resistance/resilience, improve knowledge, escalate legislative protection and coordinate management in the face of more frequent and intense wildfires.

Introduction

While the impacts of wildfires on terrestrial ecosystems are obvious, the impacts to aquatic ecosystems are less visible but can be profound and more enduring. Impacts to aquatic ecosystems can extend beyond the fire footprint, tens of kilometres downstream. Wildfires can cause mass mortality and the loss of populations but also sublethal changes to individuals, and long-lasting alteration of habitats.

Conditions leading up to the 2019–20 Australian wildfires included a prolonged 3-year drought (see Chapter 2), which stressed many aquatic ecosystems and exacerbated the subsequent impacts of wildfires. The fire footprint overlapped with many aquatic ecosystems, including upland streams and bogs, subtropical rainforest streams, lowland rivers, and streams, lakes and swamps in the sandy coastal heathlands (wallum) (Silva *et al.* 2020; Shelley *et al.* 2021). Post-fire, some burnt areas experienced higher than average rainfall, or localised but high-intensity convective storm cells, leading to severe run-off, erosion, and high streamflow, magnifying the impacts of the wildfires on these aquatic ecosystems. The consequences for aquatic fauna can be profound; direct impacts were documented for some species, while ongoing impacts are predicted for many more. The full extent and severity of these impacts, which continue to be experienced, may never be fully appreciated.

In this chapter, we summarise the effects of the 2019–20 Australian wildfires on aquatic fauna. We focus on freshwater fish and, as prominent and threatened representatives of Australian aquatic ecosystems (Furse and Coughran 2011), crayfish of the Australian endemic genus *Euastacus* ('spiny crayfish'). Other invertebrates and frogs are covered elsewhere in this book (Chapters 11 and 13 respectively). We first describe what is generally known about wildfire impacts on aquatic ecosystems, freshwater fish and spiny crayfish; we then outline the impacts of the 2019–20 wildfires, including assessments to identify species at most risk; and we document the emergency conservation efforts that took place in response to these wildfires. Finally, we summarise key lessons for improving responses to future wildfires, and improving conservation management of aquatic ecosystems and fauna.

The content presented here consolidates the efforts of many people, whose work is captured in published and unpublished sources, and aims to provide up-to-date information to understand and guide future responses when wildfires affect aquatic fauna.

How do fires impact aquatic ecosystems and species?

Wildfires are complex disturbances for aquatic ecosystems and species (Fig. 6.1). The nature and severity of impacts are context-dependent, varying with the wildfire severity as well as the characteristics and health of the aquatic ecosystem. In rivers and streams, catchment topography (i.e. slope), geology, soil porosity and degree of water repellence, vegetation condition and cover, and the frequency and intensity of subsequent storm run-off events, all influence the effect of wildfires (Legge *et al.* in press). In lake and wetland systems, the characteristics and extent of riparian and emergent vegetation cover, as well as waterbody depth, influence the severity of fire impacts on resident aquatic

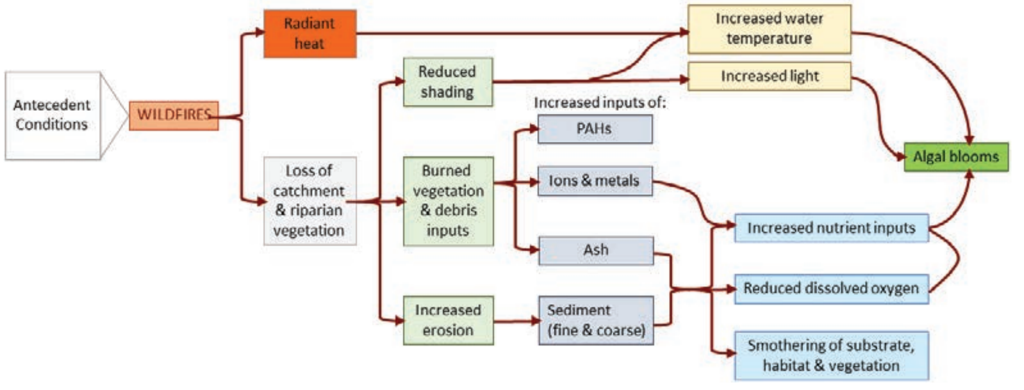

Fig. 6.1. Drivers of, and responses to, wildfires in aquatic ecosystems.

species. Antecedent conditions, such as the drought that preceded the 2019–20 wildfires, and other stressors, including habitat destruction and flow regulation, will also influence wildfire impacts. The nature of impacts varies between ecosystem types, from headwaters to lowland streams, wetlands, and estuary and marine ecosystems (Chapter 7). Importantly, post-fire run-off can create impacts that extend many kilometres downstream of the fire footprint (Lyon and O'Connor 2008; Reale *et al.* 2015; Shelley *et al.* 2021). Impacts may endure for years to decades, well beyond the actual period of the wildfire (Box 6.1). Despite this variability, some generalities are evident in the mechanisms and processes that lead to the impacts (Gomez Isaza *et al.* 2022).

Box 6.1. Physical impacts to aquatic ecosystems

The ACT Orroral Valley wildfire ignited on 27 January 2020 and burnt 88 000 ha including 80% of Namadgi National Park. The fire was extinguished on 27 February 2020 by widespread, intense rainfall (~158 mm between 10 and 14 February 2020: ACT Government 2020). The Orroral Valley wildfire was one of a series that burnt much of the upper Murrumbidgee catchment in New South Wales, and was more damaging than the extensive areas previously burnt in the 2003 Canberra fires. The rainfall that extinguished the fire caused significant sedimentation of the upper Cotter River. Mass erosion formed gullies > 2 m deep and deposited boulders, cobble, sand, silt, and ash into the stream, altering the stream course, and eroding banks which deposited more sediment. By mid-March 2020, pools at one site that were previously > 1.5 m deep had filled with sand and silt, with depth reduced to ~0.3 m; extensive sediment slugs moved down the Cotter River from upstream fire-affected areas by mid to late April 2020. Monitoring of one representative deep pool over time revealed accumulated sediment of 0.9–1.5 m depth in mid-March 2020, with maximum sediment depth slowly decreasing over 2 years to 0.95 m (Fig. 6.2) with a concomitant increase in water depth. However, recovery to pre-fire levels is expected to be slow. After the 2003 fires, pool habitats in the lower Cotter had not recovered 10 years later. Stream substrates in the 2019–20 fire-impacted reach have changed from rocky-bottomed (predominantly

Fig. 6.2. Fire-impacted pool on the upper Cotter River over time: (A) boulder and cobble from erosion gully (March 2020); (B) fine silt smothers the rocky substrate (March 2020); (C) sand persisting in stream (April 2021); and (D) sedimentation still evident 2 years post-fire (February 2022). (Photos: M. Lintermans)

cobble and boulder with some bedrock) to pebble, gravel, sand and silt. Instream aquatic vegetation is now almost absent in many areas, with previously abundant beds of water milfoil (*Myriophyllum* sp.) now smothered by sediment. The previously locally abundant population of two-spined blackfish (*Gadopsis bispinosus*) declined by ~80% immediately following the fire and sedimentation. This species is listed as Vulnerable in the Australian Capital Territory, but persists in well-forested upland streams where it relies on rocky substrates for spawning, refuge and feeding sites.

Key message: Over 2 years post-fire, aquatic habitats are still severely impacted.

During wildfire, radiant heating of the water and the immediate loss of vegetative cover can alter aquatic thermal regimes (Cooper *et al.* 2015). Extreme water temperatures, up to 55°C, can occur during wildfires (Victorian DSE 2009) with elevated temperatures (7–15°C above normal) persisting in some systems for decades until vegetation cover returns (Koontz *et al.* 2018). The rapid reduction in shading also contributes to altered primary productivity and exposes aquatic animals to greater predation threat (e.g. Rosenberger *et al.* 2015).

The largest impacts to aquatic ecosystems often occur well after the wildfire. High volume, intensity or frequency rainfall events that cause run-off across burnt, hydrophobic soils, mobilise and deposit ash-laden sediments and timber debris into aquatic ecosystems. This can alter the physical nature of aquatic ecosystems by introducing large volumes of sediment (silt, sand, gravel, pebble, cobble and boulder), by creating log jams, and altering streamflow. The ash and soil from the fireground may contain a complex milieu of nutrients (e.g. phosphorus, nitrate), ions (e.g. sodium, chloride), metals (e.g. magnesium, iron, copper) and polycyclic aromatic hydrocarbons (PAHs), which can be toxic to aquatic fauna (Cramp *et al*. 2021 and references therein). The vegetation loss reduces rainfall interception, increasing erosivity of hydrophobic burnt soils. The loss of timber debris on the forest floor reduces the ability of the riparian zone to intercept run-off and filter sediment (Reale *et al*. 2015). The influx of run-off-derived inputs into streams can adversely impact water quality, often through rapid reduction in dissolved oxygen concentrations (Lyon and O'Connor 2008). Increased sedimentation can also alter habitat suitability (through smothering), and the mobilisation of nutrients (and increased light) can promote excessive growth of aquatic plants and cause algal blooms.

How aquatic species cope with the changes to water and instream habitat quality following wildfires depends on their ability to physiologically tolerate or behaviourally adjust to these changes (Box 6.2). Aquatic organisms have a narrow range of water quality tolerances; fluctuations outside these tolerances can be lethal or impair physiological performance and fitness. For freshwater fish and spiny crayfish, abrupt or substantial changes in water temperature or oxygen concentrations affect physiological performance (Cramp *et al*. 2021) and can lead to increased predation risk, increased incidence of disease, reduced fecundity, or even kill animals. In addition, ash and sediment leachates can pose significant health problems for fish and crayfish (Gonino *et al*. 2019); however, the exact nature and composition of wildfire leachates, and therefore their potential for impact, is often highly site-specific (Harper *et al*. 2019). Ash and sediment leachates can raise water pH to > 10, compromising the ionic balance and disrupting the excretory pathways and capacities of aquatic animals. Wildfire run-off often contains ammonia, nitrate, metals (e.g. Mg, Fe, Cu, Cr, Zn, As, Pb, Hg) and polycyclic aromatic compounds, which can damage gas exchange surfaces, impair ion regulation, and impede growth and development in fish (Gomez Isaza *et al*. 2020). Furthermore, ash and sediment inputs can promote aquatic microbial activity which rapidly strips waterbodies of oxygen, suffocating fish and causing crayfish to leave the water with chronic sublethal exposure, which affects tolerance thresholds, physiology (e.g. damages respiratory structures) and behaviour (Cramp *et al*. 2021 and references therein).

Box 6.2. Physiological tolerances of aquatic species

Changes in an animal's physiological performance are useful indicators of environmental stressors and can inform biologically relevant 'tolerance thresholds' to guide management decision making (e.g. define water quality management guidelines and identify emergency triggers such as post-fire run-off mitigation or population extractions/relocations). Tolerance thresholds can also inform habitat suitability models and monitoring of species recovery. However, currently we understand little about the water quality tolerance limits of most Australian fish and crayfish, nor the potential for ash and sediment exposures to influence physiological tolerances and aerobic performance longer-term.

In response to the 2019–20 wildfires, we used laboratory-based experimental approaches to examine thermal and oxygen tolerance limits for Australian aquatic species (Cramp *et al.* 2021). We also examined the impacts of medium-term (1–2 weeks) exposure to wildfire ash leachates and fine suspended sediments on temperature and oxygen, and on the aerobic performance of aquatic species (Cramp *et al.* 2021). We found that fish and spiny crayfish from cooler high-altitude climates (e.g. mountain galaxias (*Galaxias olidus*), strong spiny crayfish (*Euastacus valentulus*), Conondale spiny crayfish (*Euastacus hystricosus*)) are likely to be at greater risk from wildfire-induced changes to aquatic thermal and oxygen regimes because their thermal and oxygen tolerance limits are up to 20% lower than those of more broadly distributed and/or lowland species. In addition, we found that chronic exposure to even very low levels of suspended ash and sediment can damage respiratory surfaces and depress thermal and oxygen tolerance thresholds by as much as 10%. This can reduce aerobic performance even in comparatively tolerant species such as olive perchlet (*Ambassis agassizzi*) and redclaw crayfish (*Cherax quadricarinatus*). These results suggest that ash and sediment may compound the negative impacts of wildfire-induced changes in water temperature and oxygen on some fish and crayfish species. Importantly, the species studied differed quite substantially in their relative sensitivity to ash and sediment-induced physiological disruptions, suggesting that post-wildfire conditions may favour species with more resilient physiologies, leading to significant changes in community composition. The multifactorial nature of wildfire impacts supports the need for informed, species-specific and adaptive management in fire-affected systems, particularly for systems containing threatened or vulnerable aquatic species.

Key message: Fish and crayfish with existing restricted, upland or temperate distributions are likely to be disproportionately affected by wildfire-induced changes to aquatic environments.

Heavier, coarse material in sediment (sand, gravel, pebble, cobble and boulder) settles out of water columns rapidly, smothering substrates and increasing stream bedload volumes, and may persist for decades. After wildfires, fine sediments in suspension can rapidly increase the total suspended solids to > 57 000 mg L^{-1} (or 5.7% solids), and turbidity levels to > 6000 nephelometric turbidity units (NTU); these sediments may remain in suspension for weeks or months, and become repeatedly re-suspended for years (Lyon and O'Connor 2008; Shelley *et al.* 2021). Suspended sediments, both coarse and fine, can clog gills, reduce feeding behaviour, and increase stress biomarkers in fish and crayfish (Kemp *et al.* 2011; Rosewarne *et al.* 2014). Ash can also alter fish behaviour by suppressing activity levels, by disrupting foraging behaviours and shoal cohesion (Gonino *et al.* 2019). If wildfire-induced run-off impacts coincide with important life-cycle processes, spawning and movement cues may be disrupted, spawning sites smothered or the survival of critical life stages, such as eggs or larvae, reduced.

Fire-fighting retardants and foams can also impact aquatic fauna. Most chemical fire suppressants are predominantly water-based, but often contain high levels of inorganic salts (e.g. diammonium phosphates and ammonium polyphosphate salts) that can liberate large quantities of ammonia if delivered directly into waterbodies; this amount of ammonia can kill aquatic fauna and exacerbate eutrophication (Boulton *et al.* 2003).

Impacts from the 2019–20 wildfires

Mortality events

Mortality of aquatic animals following the 2019–20 wildfires was widespread, documented across 26 locations in 20 waterways, over four states and territories, from headwaters to coastal areas (Silva *et al*. 2020; Shelley *et al*. 2021). Mortality was documented in 32 aquatic species, including large-bodied Murray cod (*Maccullochella peelii*) and trout cod (*M. macquariensis*), small-bodied Australian smelt (*Retropinna semoni*), non-native common carp (*Cyprinus carpio*), redfin perch (*Perca fluviatilis*) and eastern gambusia (*Gambusia holbrooki*), and estuarine species such as black bream (*Acanthopagrus butcheri*) and dusky flathead (*Platycephalus fuscus*). Mortality of the Murray spiny crayfish (*Euastacus armatus*) was observed in four waterways, and platypus (*Ornithorhynchus anatinus*) deaths were also documented. While mortality was mostly observed within areas burnt by the wildfires, freshwater fish and spiny crayfish mortality was recorded as far as 100 km downstream. Mortality events involved tens to thousands of individuals. Most mortality certainly went undetected. The mechanistic causes of observed mortality events are unknown, as are the implications of the observed (and unobserved) mortalities on the impacted species (Bino *et al*. 2021).

Predicting the species at most risk

During disturbances such as wildfire, identifying the species most at risk is critical to guide resource allocation. Following the 2019–20 wildfires, freshwater fish and spiny crayfish were prioritised through a rapid preliminary assessment (in January 2020, revised in March 2020) by the Wildlife and Threatened Species Bushfire Recovery Expert Panel, before a National Environmental Science Program project allowed for a more considered refinement of the assessment during 2021 (Legge *et al*. in press; Ward *et al*. unpublished).

For fish, the initial assessment focused on threatened species listed either internationally (International Union for Conservation of Nature (IUCN) Red List of Threatened Species), nationally (*Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)); Australian Society for Fish Biology Threatened Fishes List), or at State/Territory level, and included select undescribed species. For crayfish the focus was the highly threatened genus of spiny crayfish (*Euastacus* spp.). Use of multiple threatened listings was necessary because aquatic species are under-represented in Australian legislation (Furse and Coughran 2011; Lintermans *et al*. 2020).

A key difference between the preliminary (2020) and subsequent (2021) assessments was the inclusion of spatial variation in fire severity in the later assessment. This refinement was important because distributional overlap with fire is an imprecise indicator of the immediate fire impact. For example, a low-intensity fire may not raise water temperature and inhabitants of deep pools may be little affected. Furthermore, fire severity mapping was incorporated into an aquatic sedimentation risk model, which was created by adapting an existing erosion model to include information on fire extent and severity, and post-fire rainfall events (Legge *et al*. in press; Ward *et al*. unpublished). In contrast, the preliminary assessment relied on extending the fire extent 80 km downstream to estimate sediment pulses. This aquatic sedimentation risk model allowed for a more sophisticated characterisation of the potential aquatic impacts given fire severity and prevailing conditions (e.g. soil type, slope steepness, rainfall, and run-off) (Ward *et al*. unpublished).

Both assessments utilised the best available knowledge to define the distribution of each species, although information on the distribution and status of populations is incomplete. For freshwater fish, distributions were based on observations collated during the 2019 IUCN assessment of Australian freshwater fish (Lintermans 2019). For spiny crayfish, species distribution polygons were compiled from previous distribution data and new observations collected in 2021 during a national conservation status assessment project (Whiterod *et al.* 2022). The assessments focused on species for which the 2019–20 wildfires overlapped their range by at least 10% if listed as threatened, and at least 25% if not listed as threatened. The list of spiny crayfish species used here was refined (relative to the lists used in the assessments) to reflect taxonomic revisions and new wildfire impact knowledge. Both assessments utilised knowledge of species' behavioural, ecological and life history traits to infer susceptibility to fire impacts. However, the refined assessment also used structured expert elicitation to estimate the immediate population impact and the likely population trajectories following the wildfires (Legge *et al.* in press). We note that experts were often uncertain about fire impacts, because empirical data are few and our understanding of basic ecology and biology is incomplete for some species.

The preliminary assessment prioritised 21 threatened freshwater fish and 22 spiny crayfish taxa for management intervention (Figs 6.3, 6.4) (Legge *et al.* 2022). These 'priority' species were distributed from Victoria, throughout New South Wales and into coastal southern Queensland. Ward *et al.* (unpublished) estimated that the entire known ranges of five freshwater fish and five spiny crayfish were vulnerable to sedimentation risk following the wildfires (Fig. 6.3). Priority species included small-bodied, non-migratory, habitat specialists with restricted ranges, all traits that are linked to greater risk of extinction in aquatic species (cf. Lintermans *et al.* 2020) although several large-bodied species from the genera *Maccullochella*, *Macquaria* and *Gadopsis* were also estimated to be impacted. Impact was also predicted to be high for some broadly distributed species, such as Sutton's crayfish (*Euastacus suttoni*), with over half its range overlapping with wildfires.

The structured expert elicitation of the refined assessment highlighted the potential delayed impact from sedimentation events, as experts consistently forecast that the status of aquatic species would be worse 1 year than 1 week post-fire. Moreover, it was forecast that only partial (but not full) recovery may be realised 10 years post-fire, in part reflecting pressure from existing threats, such as drought and habitat destruction, driving prior and ongoing declining population trends of many species (Legge *et al.* in press).

The assessments relied on spatial analyses and expert elicitation, informed by empirical evidence which in some cases was limited. Regardless, it represents the best approach for using available data to rapidly guide management responses during the complex and dynamic chaos of an extended wildfire season. For most species the immediate impacts could not be measured, as access to the fire ground was impossible while fires were still active, with surveys only occurring many weeks after the fire. The 2019–20 wildfires likely pushed some aquatic species closer to extinction, including eight that were already considered to have > 50% probability of extinction in the next 20 years (Lintermans *et al.* 2020). Conservation actions to reduce extinction risk for these species is an urgent challenge. Given the predictions for increased fire frequency and severity, we need to improve our understanding of the impacts of wildfire on aquatic species, and our knowledge of the fundamental ecology of these species, to better inform similar assessments during future wildfires (and other disturbances).

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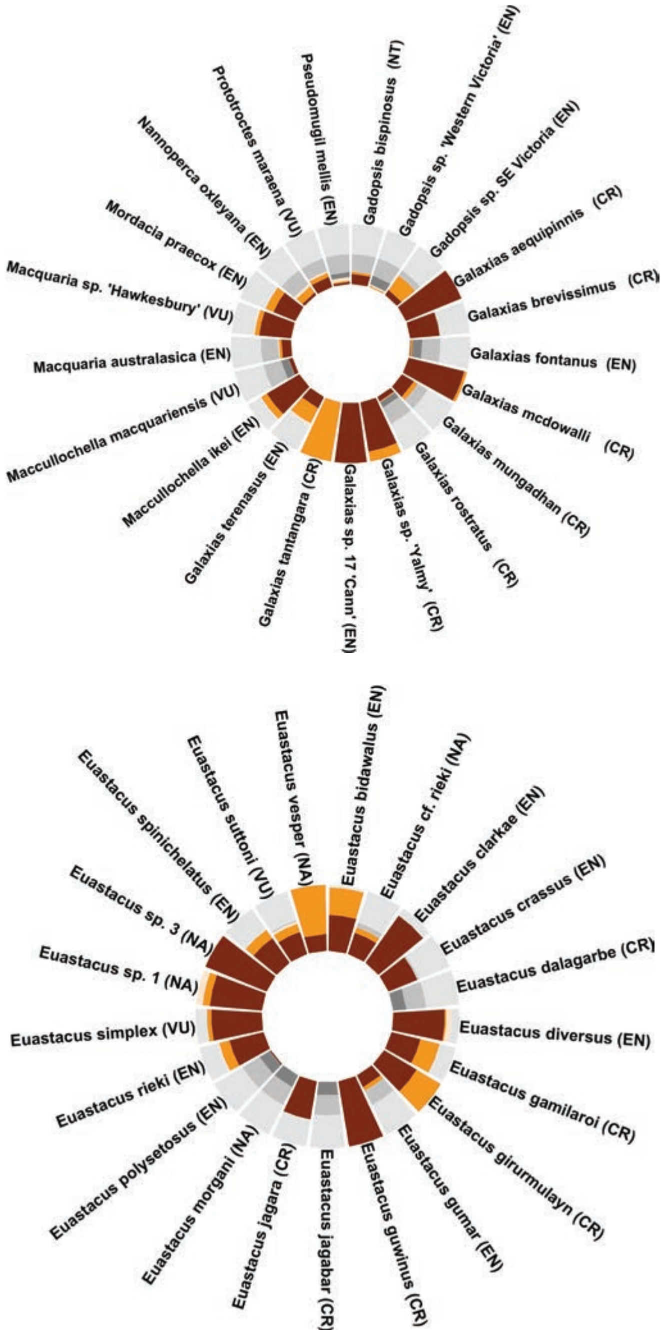

Fig. 6.3. Proportion of range at risk from sedimentation for each taxon assessed. Upper figure represents fish; lower figure is for spiny crayfish. Relative levels of risk are colour-coded as relatively mild risk (cream), relatively high risk (orange), relatively severe risk (brown) and, with background thresholds to aid visual comparisons of 30% (dark grey), 50% (medium grey) and 100% (light grey). Each taxon name includes information on their current IUCN conservation status, which can be Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), or not assessed (NA) (modified from Ward *et al.* unpublished).

Fig. 6.4. Examples of priority species impacted by the 2019–20 wildfires: Clark's crayfish (*Euastacus clarkae*) (A); Tianjara crayfish (*Euastacus guwinus*) (B); short-tail galaxias (*Galaxias brevissimus*) (C). (Photos: (A, B) Rob McCormack, (C) Tarmo A. Raadik).

Emergency conservation efforts

While the wildfires were still burning, it was clear that urgent actions were needed to prevent the loss of populations, or even the extinction, of some aquatic species. In some cases, this involved sediment control, but mostly these actions involved emergency rescue of individuals of highly restricted species from threatened streams. Animals were translocated to unimpacted waters or to *ex situ* temporary holding aquaria or aquaculture facilities until water and habitat conditions improved and they could be returned (e.g. Raadik et al. 2021). Most rescues occurred in February 2020, following substantial rainfall in late January–early February 2020 that caused widespread sediment flows. These salvage efforts were stressful to the species affected, and to the rescuers themselves, and time critical. Pragmatically the scale of these efforts was limited, but without them entire populations would have been lost, and some threatened species may have faced extinction.

Emergency actions were initiated for 24 aquatic species across three jurisdictions (Table 6.1). For five species of *Galaxias* whose entire distributions were burnt, it is possible that emergency rescue averted species extinction. Two such species, Yalmy galaxias (*Galaxias* sp. nov. 'Yalmy') and Cann galaxias (Galaxias sp. nov. 'Cann'), faced the risk of extinction before being formally described (Raadik *et al*. 2021; Stoessel *et al*. 2021). In New South Wales, emergency rescues were implemented for two other range-restricted galaxiids (stocky

Table 6.1. Species subject to salvage efforts following the 2019–20 wildfires.

Conservation status based on state listing (for the state that the work was done), national listing (*Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)) and international listing (International Union for Conservation of Nature; IUCN Red List). Conservation statuses are Critically Endangered (CR), Endangered (EN) and Vulnerable (VU). Table adapted from Shelley *et al.* (2021).

Common name	Scientific name	Conservation status			Jurisdiction where emergency rescues occurred
		State listing	EPBC Act	IUCN Red List	
Freshwater fish					
Cann galaxias	*Galaxias* sp. 'Cann'		Under assessment		Vic.
Dargo galaxias	*Galaxias mungadhan*	CR	Under assessment	CR	Vic.
East Gippsland galaxias	*Galaxias aequipinnis*	CR	Under assessment	CR	Vic.
Eastern freshwater cod	*Maccullochella ikei*	EN	EN	EN	NSW
Gippsland blackfish	*Gadopsis* sp. SEV				Vic.
Macquarie perch	*Macquaria australasica*	EN	EN	VU	NSW, Vic.
McDowall's galaxias	*Galaxias mcdowalli*	CR	Under assessment	CR	Vic.
Mountain galaxias	*Galaxias olidus*			LC	Qld
Murray cod	*Maccullochella peelii*		VU	LC	Vic.
Olive perchlet	*Ambassis agassizii*	EN*		LC	NSW
Oxleyan pygmy perch	*Nannoperca oxleyana*	EN	Under assessment	EN	NSW
River blackfish	*Gadopsis marmoratus*			LC	Qld
Short-tail galaxias	*Galaxias brevissimus*	Under assessment	Under assessment	CR	NSW
Southern purple-spotted gudgeon	*Mogurnda adspersa*	EN	Under assessment*	LC	NSW
Stocky galaxias	*Galaxias tantangara*	CR	CR	CR	NSW
Yalmy galaxias	*Galaxias* sp. nov. 'Yalmy'	Under assessment	Under assessment	CR	Vic.
Freshwater crayfish					
East Gippsland spiny crayfish	*Euastacus bidawalus*		Under assessment	EN	Vic.
Mountain crayfish	*Euastacus sulcatus*		Under assessment	VU	Qld
Orbost spiny crayfish	*Euastacus diversus*	EN	Under assessment	EN	Vic.
Variable spiny crayfish	*Euastacus yanga*	EN		LC	Vic.
Freshwater mussel					
Austral river mussel	*Hyridella australis*				Vic.
Depressed river mussel	*Hyridella drapeta*				Vic.
Glenelg freshwater mussel	*Hyridella glenelgensis*	CR	CR	CR	Vic.

* Murray–Darling Basin population

galaxias (*Galaxias tantangara*), short-tail galaxias (*Galaxias brevissimus*)) as well as large-bodied species such as eastern freshwater cod (*Maccullochella ikei*) and Macquarie perch (*Macquaria australasica*) (Box 6.3). In addition, the severe drought and wildfires prompted NSW Department of Primary Industries (Fisheries) in December 2019 to rescue 252 Oxleyan pygmy perch (*Nannoperca oxleyana*) from coastal wallum wetlands in Broadwater National Park. Other populations of Macquarie perch were rescued in Victoria and either translocated to nearby unimpacted rivers or transferred to a temporary captive facility. Mountain galaxias (*Galaxias olidus*) and river blackfish (*Gadopsis marmoratus*) were the focus of emergency rescues from Spring Creek in the upper Condamine River Catchment in Queensland. Emergency rescue was implemented for five spiny crayfish species in Queensland and Victoria.

Box 6.3. Rescuing Macquarie perch in Mannus Creek

Mannus Creek has one of only four remaining natural populations of threatened Macquarie perch (*Macquaria australasica*) in the New South Wales section of the Murray–Darling Basin. The creek was devastated by the 2019–20 wildfires, which burnt the entire known distribution for Macquarie perch in the creek (Fig. 6.5). The creek was first accessed 3 days post-fire, when the landscape was blackened and denuded, and the creek was green from an algal bloom. Despite this utter devastation, sampling revealed that some Macquarie perch had survived the blaze, but the real danger was yet to come, with forecast rain that could cause toxic run-off across the very steep and unstable catchment. Given this imminent threat, a small team worked over the next week to rescue as many Macquarie perch as possible. Despite tireless efforts, only 10 Macquarie perch were salvaged and, before extra rescue teams could arrive, a large rainstorm in the

Fig. 6.5. The impact of wildfire on Mannus Creek (A, C); a rescued Macquarie perch (B). (Photos: Luke Pearce)

catchment turned the creek into a flowing river of black sludge. Dissolved oxygen in the creek plummeted to near zero and a fish kill followed.

Surveys over the following months helped to quantify the impacts on the habitat and the fish community. Habitat mapping revealed major changes to the creek, with reduced pool depth, large amounts of burnt debris, sediment and ash deposition and loss of riparian vegetation. Initial post-fire fish surveys failed to detect any Macquarie perch, and as the rescued fish were too few to re-establish a population, they were used to supplement the genetic diversity of another remnant population. However, over time, some hope emerged with fish surveys detecting small numbers of Macquarie perch in Mannus Creek. The focus is now to reinforce this population with captive-bred fish sourced from other populations. The recovery of Macquarie perch in Mannus Creek is a long and difficult challenge that those working on the species are committed to.

Key message: Early assessment and intervention is critical, but difficult, and should be planned and resourced in advance.

Emergency conservation efforts are complex operations. In response to the 2019–20 wildfires, a chain of responsibility originating in state government agencies provided overarching guidance for those conducting the on-ground activities. Across jurisdictions, many stakeholders facilitated the emergency efforts (Shelley *et al*. 2021). On-ground rescues required several permits (including permission to access firegrounds), consideration of safety and welfare issues, and coordination with incident management teams (e.g. planning officers and operations officers), who play a critical role in providing access and logistical support (Shelley *et al*. 2021). Some species could not be assessed or extracted when roads and access tracks became impassable due to burnt trees, burnt bridges, landslides and erosion. For fish species in small, shallow streams that could be sampled easily and quickly, rescue was relatively straightforward; however, other species occupying deep habitats presented more problems. As rescued individuals were probably already stressed, transportation protocols were adapted to minimise further stress (Ebner *et al*. 2020; Shelley *et al*. 2021). Captive maintenance of animals involved strict protocols to address potential stress, disease and parasites, aggression and cannibalism, and health issues; and to ensure water quality, habitat and feeding were tailored for each species (Stoessel *et al*. 2021).

The scale of the emergency conservation effort was unprecedented, helping to avoid the loss of 24 aquatic species and populations. Releasing rescued individuals or their progeny may assist recovery. For some species, the lack of knowledge on captive husbandry and availability of suitable holding facilities made maintaining the rescued individuals problematic. Overall, the experience gained from the rescues has been invaluable (Shelley *et al*. 2021) and an important legacy could be achieving a proactive, flexible and appropriately resourced emergency rescue strategy for aquatic species. With more frequent and severe wildfires anticipated, the importance of such emergency conservation efforts will be critical for maintaining aquatic species in fire-prone regions.

Improving management of aquatic ecosystems in fire-prone regions

Several opportunities emerge – relating to prevention, preparedness, response and recovery – to better manage aquatic ecosystems and species across fire-prone regions.

Prevention: identifying and mitigating drivers

The single greatest challenge to managing wildfire impacts on aquatic ecosystems is preventing increases in the frequency and severity of wildfires, by identifying and mitigating drivers of wildfires as well as identifying areas that are more prone to the impacts of wildfires.

Preparedness: improving protection, building resilience, minimising other stressors and gaining knowledge

Some species of freshwater fish (Lintermans *et al*. 2020) and spiny crayfish are among the most threatened of all species in Australia. The prioritisation assessment (see predicting the species at most risk) drew attention to the under-representation of these taxonomic groups under national environmental legislation. Currently, only one-quarter (43) of freshwater fish and spiny crayfish species that are recognised as being of conservation concern on international, and state threatened lists, are listed under the EPBC Act (Furse and Coughran 2011). Of the wildfire-impacted species, only 10 priority fish and none of the 22 priority spiny crayfish were listed under the EPBC Act. This under-representation requires urgent rectification as it hampers the conservation of some of the most at-risk species in Australia. For instance, the current national Threatened Species Strategy (DAWE 2021) only considers EPBC-listed taxa in scope; thus 75% of threatened freshwater fish and crayfish are excluded. Fortunately, two Commonwealth funded projects are currently seeking to escalate the listing assessments for freshwater fish and spiny crayfish; this should increase attention for these species. The number of as-yet-undescribed freshwater species is also high, for example as many as 27 species of spiny crayfish (Austin *et al*. 2022). Consequently, adequate resources are needed to formally describe these candidate species, as instigating conservation management and growing community appreciation of these imperilled species is difficult without a scientific name and knowledge of distribution.

Preparing for a future with more frequent and severe wildfires will challenge the conservation of many aquatic species in fire-prone regions. Ecosystems and species at most risk need to be identified, with strategic fire management designed and implemented to lessen the impact of future wildfires (Srivastava *et al*. 2021; Legge *et al*. 2022). Resilience could be enhanced by establishing additional and/or larger populations of species to reduce extinction risk and improve evolutionary potential. Declining aquatic habitat availability and quality may be managed with actions such as restricting water extraction from refuge pools during extended dry periods, allocating more environmental flows and restoring habitat (including providing appropriate instream and overhead vegetation, rocks and logs; reducing sedimentation levels; ensuring access to burrows; and mitigating deforestation). Invasive species, both terrestrial (e.g. horses, pigs, deer, foxes, stock) and aquatic (trout, redfin, translocated native fish), should be removed and excluded from sites. Improved knowledge of the factors driving post-fire changes to aquatic ecosystems and physiological tolerances of aquatic species will provide a more holistic picture of the likely consequences of increasing wildfire frequency and severity on aquatic ecosystems.

In the wake of the 2019–20 wildfires, funding was directed towards knowledge generation for aquatic species (Box 6.4); this needs to be sustained. This includes establishing long-term monitoring programs to allow robust assessment of the impacts of, and recovery following, wildfires (Southwell *et al*. 2022). In addition to emergency rescue, facilities for short- and long-term captive maintenance and breeding along with translocation may have merit for high-risk species. These management interventions should be implemented in accordance with best practice (e.g. IUCN/SSC 2013) to ensure conservation responses are effective, ethical, socially acceptable and minimise ecological and environmental risks.

Box 6.4. Collaborative project to inform the recovery of spiny crayfish

'Saving the Spinys' was a multifaceted collaborative project, involving crayfish experts from eight organisations, which aimed to inform the recovery of wildfire-impacted spiny crayfish. Field surveys helped to resolve the contemporary range and identify key populations and threats for all 22 priority spiny crayfish species. The project also facilitated the most comprehensive molecular taxonomic analyses ever conducted on spiny crayfish (Austin *et al.* 2022), and the application of environmental DNA (eDNA) to define the range of species enable tracking of population trajectories over time. Zukowski *et al.* (2021) identified conservation translocations as an important management tool for spiny crayfish, although more species-specific investigation is warranted. The knowledge gained through the project enabled formal description of new species, guided assessment of priority species under national EPBC Act legislation and allowed for an action plan to be developed. By redressing long-standing knowledge gaps, Saving the Spinys will establish a platform for the conservation of spiny crayfish for decades to come.

The small crayfish (*Euastacus spinichelatus*) showcases how the project informed conservation of a wildfire-susceptible species (Fig. 6.6). Formally described in 1997,

Fig. 6.6. The small crayfish (*Euastacus spinichelatus*) sampled during post-fire surveys. (Photo: Rob McCormack)

the molecular taxonomic analyses of Austin *et al.* (2022) confirmed its validity and identified two divergent and geographically disjunct lineages. Field surveys revealed the loss of the species from several sites (including the type locality) following the 2019–20 wildfires. Two years on, the species has not naturally recolonised these sites despite the forest regenerating and streamflows normalising; reintroductions may be possible (Zukowski *et al.* 2021). The small crayfish is forecast to be listed as Endangered under the EPBC Act (Whiterod *et al.* 2022), with the projected increase in wildfire frequency and severity a key threat. While many knowledge gaps have been filled, the new focus is investigation and description of the two divergent lineages.

Key message: Proactive strategic assessments for poorly known taxonomic groups will help fill knowledge gaps and establish priorities for future conservation responses.

Response: emergency management to mitigate

The 2019–20 wildfire experience led to several recommendations for future improvement, including creating a dedicated emergency fund in each jurisdiction to allow for time-critical, coordinated conservation responses (Shelley *et al.* 2021). Stakeholders need access to relevant information and training to be ‘emergency-ready’ and permits and approvals need to be processed rapidly. The capacity of existing fish hatcheries and aquariums to support and assist emergency captive management programs should be enhanced, or purpose-built facilities should be established. Long-term collaborative relationships between conservation managers and emergency agencies are required to ensure future responses are feasible. The prioritisation of resources will increasingly be necessary as the 2019–20 wildfires highlighted the fact that not all populations can be saved.

Recovery: overcoming the impacts to ecosystems and species

Helping aquatic species to recover from wildfires will require targeted implementation of threat abatement, habitat protection and enhancement, and *ex situ* conservation (and translocations) actions (Geary *et al.* 2022; Legge *et al.* 2022). These actions should occur in both burnt and unburnt areas, which are refuges and sources of dispersal to assist recovery. The recovery outlook for freshwater fish and spiny crayfish is considered to be poorer than for other taxonomic groups (Legge *et al.* in press). Improving our ecological knowledge of these species should help our ability to manage them. Better identifying high-risk areas and species likely to be present will be necessary to refine the blueprint for emergency responses (Legge *et al.* 2022).

Conclusions

The impacts of the 2019–20 wildfires will endure in aquatic ecosystems for decades. The consequences may be irreversible for some taxa. While the conservation responses to the wildfires may have supported recovery in some aquatic fauna, recovery is generally anticipated to be slow and future wildfires will create additional risks. Sustained investment and attention are needed to measure and support recovery, and to increase preparedness for future events.

Recommendations

While these recommendations have been developed with freshwater fish and spiny crayfish in mind, they are equally relevant to other wildfire-prone freshwater species.

- Build the resilience of freshwater species to future wildfires by reducing other stressors, protecting and enhancing habitat, expanding distributions and increasing population sizes.
- Establish conservation facilities to house insurance populations and facilitate emergency rescues.
- Undertake statutory listing assessments of threatened freshwater fish and spiny crayfish (including those impacted by wildfires); encourage greater incorporation of EPBC Act-listed species into national and regional strategies.
- Pending the comprehensive updating of aquatic species in EPBC listings, adopt the approach used in the initial fire impact prioritisation process of using all threatened species lists when considering priority species for management/conservation.
- Resource and implement long-term monitoring and research programs for fire-impacted ecosystems and species to address knowledge gaps.
- Streamline the ability to rapidly react by establishing a centrally coordinated and appropriately funded response framework to enable time-critical and strategic conservation responses to catastrophic disturbances such as wildfires (as well as floods and droughts).

Addressing these recommendations will help to improve the future management of aquatic fauna in response to wildfires, and improve the conservation of these 'underwater, out of sight' Australian aquatic fauna.

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