Threatened Species Recovery Hub

National Environmental Science Programme

Summary of the 2019/20 bushfire impacts on freshwater fish and emergency conservation response in south-eastern Australia

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August 2021

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Cite this publication as: Shelley, J.J., Raadik, T.A., and Lintermans, M., 2021. Summary of the 2019/20 bushfire impacts on freshwater fish and emergency conservation response in south-eastern Australia. NESP Threatened Species Recovery Hub Project 8.3.6 update report, Brisbane.

Acknowledgements

We would like to acknowledge the valiant efforts of all those who took part in and facilitated the aquatic response to the 2019/20 bushfires. Furthermore, we thank those that generously contributed their time to provide us information for this report. We also acknowledge the help of Daniel Stoessel (Arthur Rylah Institute for Environmental Research) in compiling this report.

Front cover image: A stream in East Gippsland impacted by fire and debris flow. Image: Daniel Stoessel.

Contents

Summary

Climate change is increasing the frequency and duration of climatic conditions conducive for very large bushfires that result in widespread and severe impacts on both terrestrial and aquatic ecosystems. Large fire events are increasing across forested regions globally and this upward trend is projected to continue in south-eastern Australia. Therefore, there is an increasing need for conservation bodies to be adequately prepared to respond to this threat.

In aquatic ecosystems, bushfires lead to drastic declines in habitat quality that can cause sudden mass mortality events across a range of resident fauna, and consequently influence the extinction risk of species. The main mechanism of impact on aquatic fauna is the flow of debris and sediment from burnt catchments into streams during rainfall events that follow the fires. Between mid-2019 and mid-2020, Australia experienced an unprecedented fire season. South-eastern Australia was the worst affected with around 7.8 million hectares of forest being burnt. Most fire effected areas then experienced higher than average rainfall that led to widespread debris/sediment flows and consequent mass mortality of aquatic fauna.

In response to this extraordinary event, research and conservation agencies and individuals across the Australia's south-eastern States and Territories coordinated a range of conservation efforts aimed at assessing the risk posed to species and/or important populations of fish, crayfish, mussels and salvaging those that were deemed to be immediately threatened with extinction. These efforts included rescues, translocations and captive management programs that targeted 16 species of fish, five species of crayfish, and two species of mussel. The magnitude of this event, the number of species needing intervention efforts, and the speed at which the response had to be coordinated was unprecedented, testing the emergency conservation response systems in place across the impacted jurisdictions. There is a critical need to collate these responses and assess their efficiency and effectiveness so that successes and failures can be learnt from and Australia's conservation response to large fires can improve.

In this report we collated available information on (1) the impacts of the bushfires in south-eastern Australia on aquatic fauna, evidenced through mass mortality events and water quality data, and (2) the conservation response to such impacts. We sought records of aquatic mortality events and water quality data from government databases and water scientists and gained insight into the emergency conservation response by interviewing 11 of the staff involved.

We compiled a list of aquatic mortality events from 26 locations in 20 waterways spread across NSW, Victoria, ACT and Queensland. The events involved 32 species of fish, crayfish and mammal from both freshwater and estuarine environments, and they were observed as far as 70 km downstream of the fire area. Water quality readings in the vicinity of these events showed massive spikes in turbidity (up to 5833 NTU) and rapid and sometimes prolonged falls in dissolved oxygen to anoxic levels immediately following the fires. Oxygen levels stabilised within six months at most sites but kept dropping to anoxic levels throughout the year following the fires at one site. Turbidity remained high at all sites and kept spiking over the following year.

We collate information on 25 conservation projects that were conducted across three jurisdictions aiming to salvage species and populations from threatened habitats and hold them in temporary captivity until conditions improved and they could be returned. Based on the input provided by staff working on each of these projects, with full acknowledgement of the immense effort made by all of those involved in the bushfire response under extraordinary conditions, we make ten recommendations on actions that could be taken to improve the effectiveness and efficiency of such emergency responses in the future. This report and its recommendations are designed to provide aquatic biodiversity managers the opportunity to reflect on what happened and ensure that we are as prepared as possible for the future.

Introduction

Globally, freshwater ecosystems are among the most threatened, with habitat modification, and introduced species considered the major threats (Arthington et al. 2016; Kearney et al. 2019). Furthermore, climate change is an emerging threat that is predicted to drastically alter rainfall, streamflow and temperature regimes that have an overarching influence on the availability of freshwater and its quality as habitat (Ficke et al. 2007; Morrongiello et al. 2011; Reid et al. 2019). Adding to this, climate change is increasing the frequency and duration of climatic conditions conducive for very large bushfires that result in widespread and severe impacts on both terrestrial and aquatic ecosystems (Ward et al. 2020; Collins et al. 2021). These events are increasing across forested regions globally and this upward trend is projected to continue in many regions, including south-eastern Australia (Turco et al. 2018; Clarke et al. 2020; Abatzoglou et al. 2021). Therefore, there is an increasing need for conservation bodies to be adequately prepared to respond to this threat.

In aquatic ecosystems, bushfires lead to drastic declines in habitat quality that can cause sudden mass mortality events across a range of resident fauna, and consequently influence the extinction risk of species (Bixby et al. 2015; Silva et al. 2020). While aquatic environments may be somewhat buffered from the direct impacts of fire such as extreme high temperatures, the impact of debris and sediment flow from burnt catchments into streams during rainfall events that follow the fires causes widespread devastation (Emelko et al. 2016; Ward et al. 2020; Ball et al. 2021; Reale et al. 2021). The slurry of ash and soil washed into the streams causes massive, rapid rises in suspended solids that clog the gills of aquatic animals preventing respiration, while the increased carbon input leads to steep declines in dissolved oxygen that may also lead to suffocation (Bozek and Young 1994; Lyon and O'Connor 2008; Silva et al. 2020). Other elements resulting from ash and soil being washed into waterways (e.g. fire retardant dropped by firefighters, nitrogen and phosphorus, and heavy metals from ash and sediments) may also have detrimental impacts on aquatic animals (Adams and Simmons 1999; Harper et al. 2019). The effects of large and high severity burns on hydrology, geomorphology, and water quality are widespread and episodic (Shakesby and Doerr 2006; Reale et al. 2015; Rhoades et al. 2019) and subsequently alter downstream biotic communities (algae to fish), food webs, and ecosystem processes (Minshall et al. 1989; Bisson et al. 2003; Bixby et al. 2015).

Freshwater fauna are particularly vulnerable to such threats as they are isolated within the terrestrial landscape and cannot easily relocate from impacted areas (Fausch et al. 2002). The insular nature of aquatic habitats has led to the evolution of many species with narrow geographic ranges, many confined to a single lake or river catchment (e.g. Adams et al. 2014; Raadik, 2014, Shelley et al. 2018; Lintermans et al. 2020). Previously widespread species become fragmented in distribution as various populations go extinct and natural recolonisation doesn't occur. The result is highly endemic and isolated communities that are particularly susceptible to environmental change (Strayer and Dudgeon 2010). As a direct consequence of the vulnerability of aquatic ecosystems, freshwater fishes are the most threatened group of vertebrates on Earth behind amphibians (Sala et al. 2000); the estimated global extinction rate of fishes exceeds that of all higher vertebrates (Ehrlich 1994; Bruton 1995). Evidence of this decline is prominent in Australia, where 36% of 242 freshwater fish taxa assessed in 2019 were classified as threatened and another 8% were Near Threatened or Data Deficient (IUCN 2021).

Between mid-2019 and mid-2020, Australia experienced an unprecedented fire season where more than 10 million hectares of forest was burnt, including ~7.8 million hectares of mainly temperate forest in south-eastern Australia alone (Davey and Sarre 2020). This was the largest area burnt in a single fire season in south-eastern Australia since European occupation (Wintle et al. 2020). Most fire affected areas subsequently experienced higher than average rainfall in late Summer that lead to widespread debris/flows and consequent mass mortality of aquatic fauna (e.g. Silva et al. 2020). However, the full extent and severity of impacts following rainfall has not yet been documented.

In response to this extraordinary event, research and conservation agencies and individuals across the States and Territories impacted by the fires coordinated a range of conservation efforts aimed at assessing the risk posed to species and/or important populations of fish, crayfish, mussels and salvaging those that were deemed to be immediately threatened with extinction. These efforts included impact assessments (desktop and on-ground) (e.g. Legge et al. 2020), rescues, translocations and captive management programs ultimately targeting 16 species of fish, five species of crayfish, and two species of mussel. While similar efforts have been conducted in Australia to save aquatic species threatened with localized or complete extinction (Bond et al. 2008; Raadik et al. 2010; Koehn et al. 2013; Hammer et al. 2013; Lintermans 2013; Lintermans et al. 2014; Todd and Lintermans 2015; Lintermans et al. 2015; Moy and Unmack 2017; Stoessel et al. 2020), the magnitude of this event, the number of species needing intervention efforts, and the speed at which the response had to be coordinated was unprecedented. The impact of the fires on aquatic fauna and the efforts of those trying to save impacted species gained significant national and international media attention (see Appendix A1), and community support, drawing freshwater conservation into the spotlight, which was somewhat unfamiliar but overdue. The agencies and individuals involved in the response fell across four different States and Territories (New South Wales [NSW], Victoria, Queensland, and the Australian Capital Territory [ACT]), and thus co-ordinated their respective efforts under different governmental and organisational structures and with varying funding, personnel, and infrastructure constraints. It is therefore important to collate these responses and assess their efficiency and effectiveness so that successes and failures can be learnt from and Australia's conservation response to large fires can improve as a whole ahead of future events.

In this report we collate information to provide (1) a snapshot of the impacts of the bushfires in south-eastern Australia on aquatic fauna, evidenced through mass mortality events and water quality data, and (2) an overview of the conservation response to such impacts. We sought records of aquatic mortality events and water quality data from government databases and gained insight into the conservation response by interviewing some of the staff involved. We focus on the emergency response that took place during and immediately after the fires rather than subsequent efforts related to recovery and rehabilitation. Also, we focus on decision making by ground staff and the organisation directly involved in the conservation actions, rather than at higher organisational levels.

Using this information, we aim to: (1) map short-term impacts of the 2019/20 fires on fish (i.e. the location, timing, severity and species composition of fish kills) and water quality; (2) identify and summarise emergency interventions that were conducted; and (3) identify factors that hindered or helped such emergency interventions. We then provide recommendations for future adoption in emergency conservation actions aimed at aquatic fauna.

1. Approach

1.1 Aquatic mortality events

Investigating the effects of naturally occurring landscape-scale disturbances, such as bushfires, on riverine fish assemblages is difficult due to the sporadic nature of the events and the scarcity of long-term monitoring data collected at an appropriate spatial and temporal resolution to assess the assemblage response. Therefore, to conduct a broad assessment of the impact of the 2019/20 bushfires on aquatic fauna, we focussed on the acute impact of the fires observed through aquatic mortality events. Aquatic mortality events, often referred to as fish kills, refer to the sudden and substantial localised die-off of aquatic fauna. They are typically caused by a rapid reduction in water quality (e.g. lowered oxygen levels; increased turbidity or water temperatures) and can be easily observed as dead animals often float on the water's surface or are washed up on stream banks (e.g. Moritz et al. 2019). State governments within each Australian jurisdiction record aquatic mortality events reported to them internally or by the public. Furthermore, jurisdictions in the Murray–Darling Basin (MDB) have an obligation to report aquatic mortality events within the MDB to Murray–Darling Basin Authority (MDBA). Some aquatic mortality events are not reported to government but may be reported on in the media (e.g. news platforms and blog posts). We collated information on aquatic mortality events from the relevant governmental bodies and by online searches for aquatic mortality events in the media. We also cross-checked this information against the preliminary list of aquatic mortality events presented in Silva et al. (2020) that focussed on NSW.

1.2 Water quality

We sought out water quality data from fire-affected catchments with the aim of characterising the impact of post-fire sediment flows on the aquatic environments. We contacted government, private and non-for-profit environmental agencies (i.e. NSW Waterwatch) across each jurisdiction and interrogated public databases including the Water Measurement Information System (Victoria), Real-time water data (waternsw.com.au) (NSW), and WMIP: Queensland Government (information.qld.gov.au) (Queensland). We focused on turbidity and dissolved oxygen as they are most commonly cited as the cause of mortality of aquatic fauna from post-fire sediment flows. Our criteria for datasets were that they were: (1) continuous (logger data); (2) recorded before and after the bushfires; and (3) recorded at least Dissolved Oxygen (DO), Turbidity, and Discharge. However, these data proved difficult to find and likely do not exist for most of the affected catchments. While we found one dataset that met these criteria (from Tambo River at Battens Landing), others only met some criteria but were considered useful in achieving our aim.

1.3 Emergency interventions and their relative success

We collated information on aquatic fauna responses via direct communication with organisations and individuals involved in the post-fire aquatic conservation response (e.g. Government agencies and contractors). We collated a list of the various emergency response projects conducted, then identified key staff who managed and conducted those projects. Once contact was made, we provided a questionnaire for these staff to complete (Appendix A2) which aimed to capture the details of emergency response projects from inception to completion. They focussed on aspects of management structure, process, preparedness, capacity, and effectiveness. The questionnaires were followed up a with a phone interview to clarify and elaborate on various responses. Ultimately, we received responses from 11 people involved in each of the aquatic conservation projects identified in Section 4.

2. Short-term impacts to fish and aquatic habitats following the 2019/20 bushfires

At least 32 species (fish, crustacean and mammal) were recorded among aquatic mortality events linked to the 2019/20 bushfires, including the conservation-listed Murray Cod (*Maccullochella peelii*), Trout Cod (*M. macquariensis*), and Platypus (*Ornithorhynchus anatinus*). These events were reported from 26 locations in 20 waterways spread across NSW, Victoria, ACT and Queensland. Many smaller mortality events likely occurred but remain unreported. The largest number of species reported as killed was in the upper Murray River region on the NSW–Victoria boarder (9 species; site 13 Table 1 and Figure 1), and Macleay River in north-eastern NSW (eight species; site 4 Table 1 and Figure 1), with small (e.g. Australian smelt; *Retropinna semoni*) to large (e.g. Murray Cod) species being impacted. Several short, steep south-east coast catchments that drain from the Great Dividing Range were burnt from their headwaters to the coast and substantial mortality of freshwater and estuarine species (hundreds of fish, 11 species, seven locations) was reported (sites 7 to 11 Table 1 and Figure 1). Mortality events predominantly occurred within or close to fire zones, but some extended far downstream. For instance, an event was recorded ~60 km downstream of the fire boundary in the Dumaresq River and ~70 km downstream in the upper Murray River (Figure 1). Similarly, following the large 2003 bushfires that impacted the upper Ovens River catchment in Victoria, Lyon and O'Connor (2008) observed dead and stressed fish 80 km downstream of the fire zone, illustrating the geographic extent of bushfire impacts on aquatic environments.

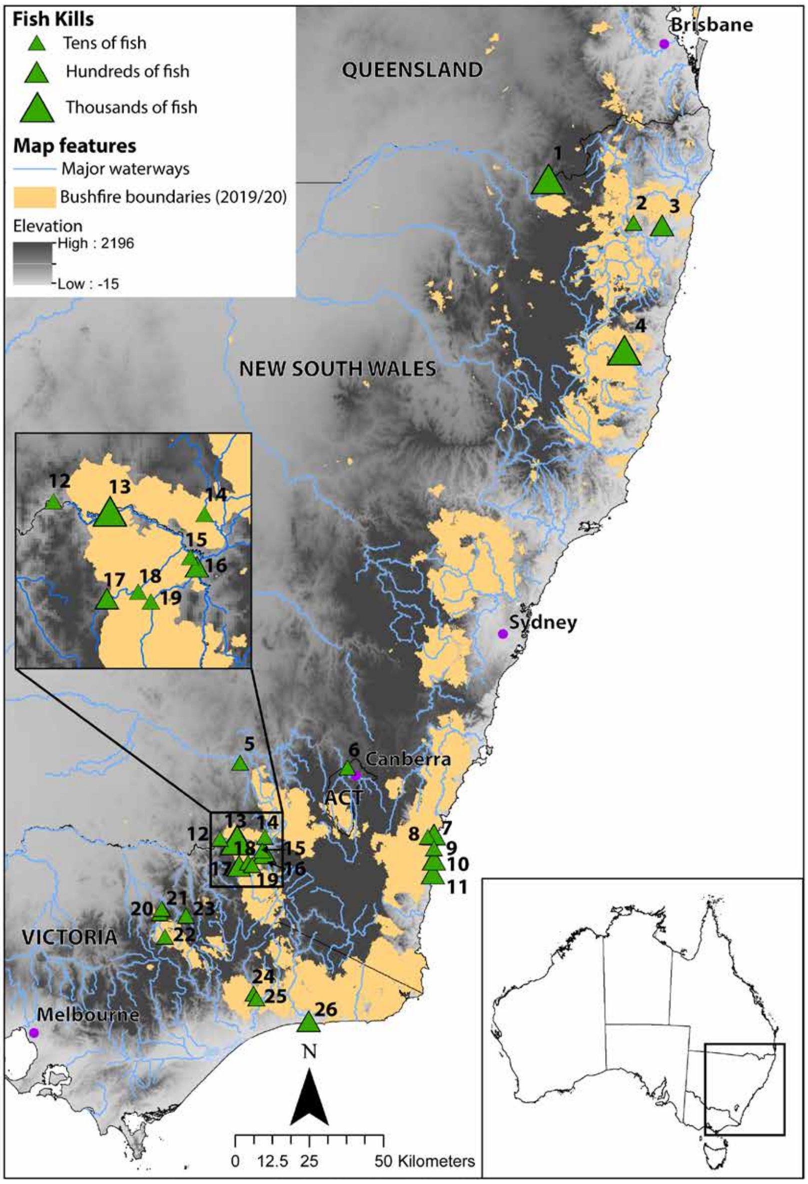

Figure 1. Map of Australia showing locations of reported fish kills related to the fires and fish recovery actions undertaken by each jurisdiction.

Table 1. Details of fish kill incidents in south-eastern Australia attributed to the 2019/20 bushfires, with information on the species impacted, their origin (Ex, Exotic; N, native), habitat (E, estuarine; F, freshwater), and conservation status, and the overall number of individuals reported (*N* = 10s, 100s or 1,000s).

These species were observed dead in the streams with their deaths attributed to debris flow from nearby fires. Information was sourced from media or government agencies (Source). Conservation status is based on the Australian Environmental Protection and Biodiversity Conservation (EPBC) Act List of Threatened Fauna and the IUCN Red List of Threatened Species (*).

Waterway	Location	Extent	Scientific name	Common name	Origin	Habitat	Conservation status	N	Source
Dumaresq River	1. Between Tenterfield Creek and Beardy River, Qld/NSW	~23 km	*Maccullochella peelii* *Tandanus tandanus* *Cyprinus carpio* Unknown *Macrobrachium* sp. *Paratya* sp.	Murray Cod Freshwater Catfish Common Carp Small fish species Freshwater prawn Freshwater shrimp	N N Ex N/A N N	F F F F F F	Vulnerable Least concern * N/A N/A N/A N/A	1000s	NSW DPI- Fisheries and Qld DNRM [a]
Clarence River	2. Grafton, NSW	Single location	Not identified	N/A	N/A	N/A	N/A	10s	NSW DPI- Fisheries
Sportsmen Creek	3. Sportsmen Creek, NSW	Single location	*Trachystoma petardi* *Percalates colonorum* Unknown	Freshwater Mullet Estuary Perch Herring	N N N	F/E E F/E	Least concern * Least concern * N/A	100s	NSW DPI- Fisheries [b]
Macleay River	4. Belbrook to Kempsey, NSW	~54 km	*Anguilla* sp. *Percalates novemaculeatus* *Aldrichetta forsteri* *Trachystoma petardi* Unknown *Gobiomorphus australis* *Tandanus* *Notesthes robusta*	Eel Australian Bass Yelloweye Mullet Freshwater Mullet Herring Striped Gudgeon Freshwater Catfish Bullrout	N N N N N N N N	F/E F/E E F/E F/E F/E F F/E	N/A Least concern * Least concern * Least concern * Least concern * Least concern * Least concern * Least concern *	100s	Media (The Guardian and NSW DPI-Fisheries) [b]
Tarcutta Creek	5. Windamarra Road, Borambola, NSW	Single location	*Euastacus armatus* *Maccullochella peelii* *Macquaria ambigua* *Cyprinus carpio*	Murray Crayfish Murray Cod Golden Perch Common Carp	N N N N	F F F F	Data deficient * Vulnerable Least concern * N/A	10s	NSW DPI- Fisheries [a,b]
Ginninderra Creek	6. Canberra, ACT	Single location	*Cyprinus carpio* *Perca fluviatilis*	Common Carp Redfin Perch	Ex Ex	F F	N/A N/A	10s	Online report (Umbagong Landcare Group) [c]
Deua River	7. Upstream of Moruya, NSW	Single location	*Percalates novemaculeatus* *Anguilla* sp.	Australian Bass Eel	N N	F/E F	Least concern * N/A	10s	NSW DPI- Fisheries [b]
Tuross Lake	8. Tuross Head, NSW	Single location	*Trachystoma petardi* *Acanthopagrus butcheri* *Sillago* sp. Unknown	Freshwater Mullet Black Bream Sand Whiting Black coloured fish	N N N N	F/E E E F/E	Least concern * Least concern * N/A N/A	10s	NSW DPI- Fisheries [b]

Waterway	Location	Extent	Scientific name	Common name	Origin	Habitat	Conservation status	N	Source
Tilba Lake	9. South of Narooma, NSW	Single location	*Sillago* sp. *Girella tricuspidate* *Acanthopagrus butcheri* *Platycephalus fuscus* *Anguilla* sp.	Sand Whiting Luderick Black Bream Dusky Flathead Eel	N N N N N	E E E E F/E	N/A N/A Least concern * N/A N/A	100s	Newspaper article (Sydney Herald) [d]
Moruya River	10. Shelley Beach, NSW	Single location	*Portunus armatus* Unknown Unknown Unknown	Blue swimmer crab Flounder Anglerfish Kingfish	N N N N	E E E E	N/A N/A N/A N/A	100s	NSW DPI- Fisheries [b]
Mummaga Lake	11. Dalmeny, NSW	Single location	*Tetractenos hamiltoni*	Common Toadfish	N	E	Least concern *	100s	NSW DPI- Fisheries [b]
Lake Hume	12. Hume Dam entrance, Vic.	Single location	*Cyprinus carpio*	Common Carp	Ex	F	N/A	10s	EPA Vic.[e]
Murray River	13. Jingellic to Talmalmo, Vic./NSW	~70 km	*Euastacus armatus* *Macrobrachium* sp. *Paratya* sp. *Maccullochella macquariensis* *Maccullochella peelii* *Gadopsis marmoratus* *Macquaria ambigua* *Retropinna semoni* *Perca fluviatilis*	Murray Crayfish Freshwater prawn Freshwater shrimp Trout Cod Murray Cod River Blackfish Golden Perch Australian Smelt Redfin Perch	N N N N N N N N Ex	F F F F F F F F F F	Data deficient * N/A N/A Endangered Vulnerable Least concern * Least concern * Least concern * N/A	1000s	NSW DPI- Fisheries and EPA Vic. [b,e]
Mannus Creek	14. Bogandyera Nature Reserve, NSW	Single location	*Paratya* sp. *Maccullochella peelii* *Cyprinus carpio* *Gambusia holbrooki*	Freshwater shrimp Murray Cod Common Carp Mosquito Fish	N N Ex Ex	F F F F	N/A Least concern * N/A N/A	100s	NSW DPI- Fisheries [a]
Horse Creek	15. Tintaldra, Vic.	Single location	*Maccullochella peelii* *Maccullochella macquariensis* *Cyprinus carpio*	Murray Cod Trout Cod Common Carp	N N Ex	F F F	Vulnerable Endangered N/A	10s	EPA Vic.[e]
Corryong Creek	16. Towong, Vic.	Single location	*Euastacus armatus* *Maccullochella peelii* *Cyprinus carpio*	Murray Crayfish Murray Cod Common Carp	N N Ex	F F F	Data deficient * Vulnerable N/A	100s	NSW DPIE- Fisheries and EPA Vic. [b,e]
Corryong Creek	17. Nariel, Vic.	Single location	Not identified	N/A	N/A	N/A	N/A	10s	Cameron McGregor (personal observation)
Cudgewa Creek	18. Cudgewa, Vic.	Single location	*Maccullochella peelii* *Gadopsis* sp. *Cyprinus carpio*	Murray Cod Blackfish Common Carp	N N Ex	F F F	Vulnerable N/A N/A	10s	Cameron McGregor (personal observation)

Waterway	Location	Extent	Scientific name	Common name	Origin	Habitat	Conservation status	N	Source
Cudgewa Creek	19. Berringama, Vic.	Single location	*Euastacus armatus* *Maccullochella peelii* *Cyprinus carpio* *Ornithorhynchus anatinus*	Murray Crayfish Murray Cod Common Carp Platypus	N N N N	F F F F	Data deficient * Vulnerable N/A Near threatened *	100s	NSW DPI- Fisheries and EPA Vic. [b,e]
Buffalo River	20. Nug Reserve, Vic.	Single location	*Maccullochella peelii* Unknown	Murray Cod Crayfish	N N	F F	Vulnerable N/A	10s	Katherine Doyle and Cameron McGregor (personal observation) [a]
Buffalo River	21. Downstream Lake Buffalo, Vic.	Single location	*Maccullochella peelii*	Murray Cod	N	F	Vulnerable	10s	Katherine Doyle and Cameron McGregor (personal observation) [a]
Buffalo River	22. Abbeyard, Vic.	Single location	*Oncorhynchus mykiss*	Rainbow Trout	Ex	F	N/A	10s	Katherine Doyle and Cameron McGregor (personal observation)
Ovens River	23. Bright, Vic.	Single location	Unknown	Trout	Ex	F	N/A	10s	EPA Vic.[e]
Tambo River	24. Tambo Crossing, Vic.	Single location	*Anguilla* sp.	Eel	N	F/E	N/A	10s	ABC News [f]
Tambo River	25. Double Bridges, Vic.	Single location	*Anguilla* sp. *Cyprinus carpio*	Eel Common Carp	N Ex	F/E F	N/A N/A	10s	EPA Vic. [e]
Brodribb River	26. Marlo, Vic.	Single location	Unknown	N/A	N/A	N/A	N/A	100s	EPA Vic. [e]

Abbreviations: ? = unknown information; N/A = not applicable; NSW = New South Wales; Vic. = Victoria, Qld = Queensland; ARI = Arthur Rylah Institute for Environmental Research.

[a] Murray Darling Basin Fish Death Incident Log, unpublished data

[b] NSW Fisheries Fish Kills Reports—https://www.dpi.nsw.gov.au/fishing/habitat/threats/fish-kills

[c] Southern ACT Catchment Group—https://sactcg.org.au/blackwater-and-fish-kill-events-in-the-act/

[d] ABC News—https://www.abc.net.au/news/2020-01-23/eels-found-dead-in-polluted-tambo-river/11893646

[e] Environmental Protection Authority Victoria Fish Death Report Log, unpublished data

[f] The Guardian—https://www.theguardian.com/world/2020/jan/17/hundreds-of-thousands-of-fish-dead-in-nsw-as-bushfire-ash-washed-into-river

Water quality data collected at several locations displayed severely degraded water quality following post-fire rain events. Sediment and ash washed into the watercourses following large rainfall events lead to massive rises in turbidity and sharp declines in DO to anoxic levels, that often coincided with each other. The water quality monitoring site on the Tambo River at Battens Landing (Figure 2) was operating prior, during, and following the fires that impacted on the catchment and provides the clearest example of the impact. In the year prior to the fires (1st January 2019 – 30th December 2019) the mean turbidity was 36.6 NTU and rarely exceeded the Australian and New Zealand Environment Conservation Council (ANZECC) guideline for aquatic ecosystems (50 NTU), while DO levels never fell below 2.0 ppm. However, immediately following the fires (between 31st December 2019 and February 22nd) and a modest rise in stream discharge, DO dropped to anoxic levels on three occasions which coincided with large spikes in turbidity (560 to 1963 NTU). Two aquatic mortality events were observed on the Tambo River on the 8th January 2020 and 23rd January 2020 ~30 km upstream of these water quality readings, within the fire boundaries where conditions were likely worse, and it is expected that these water quality conditions were the cause. The most extreme conditions followed a peak in discharge in late February 2020 that coincided with a drop in DO to anoxic levels (< 2.0 ppm) for three days, reaching 0.25 ppm at the lowest point, before rebounding to typical concentrations (> 5.0 ppm) the following day. Simultaneously, turbidity peaked at 1963 NTU, ~54x the largest peak experienced in the year prior to the fires, before falling again. After the first rainfall events, DO remained stable for the rest of the year. However, turbidity remained above the ANZECC guideline and continued to experience large peaks (> 500 NTU) for at least a year following the fires.

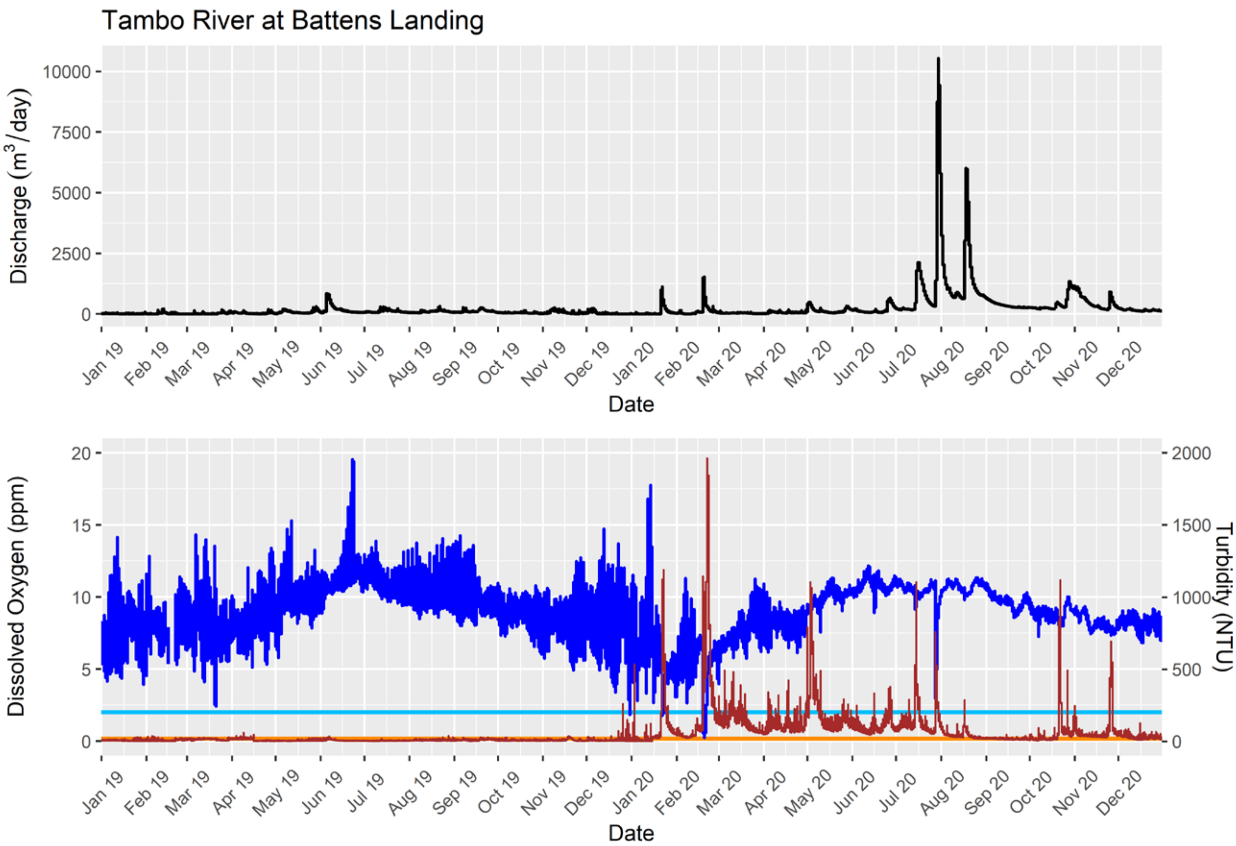

Figure 2. Stream discharge (black), dissolved oxygen (blue) and turbidity (brown) readings at Battens Landing, Tambo River, Vic within the Snowy River Fire complex in the year prior to and following the beginning of those fires (January 1st 2019 to December 31st 2020).

Orange line = guideline turbidity value for aquatic ecosystems (50 NTU) from the Australian and New Zealand Environment Conservation Council guidelines for fresh and marine water quality (ANZECC 2000); Light blue line = dissolved oxygen threshold for anoxic conditions (2.0 ppm). Note that loggers were placed at varying times following the fires.

Three water quality loggers that were placed in the Upper Murray-Walwa Fire area, soon after those fires were extinguished, provide further insight into the intensity and longevity of the debris/sediment flow impacts. Corryong and Cudgewa creeks experienced several high rainfall events throughout the year that lead to steep increases in discharge. These increases coincided with extreme peaks in turbidity, with the highest being 5825 NTU and 6247 NTU respectively. While the mean turbidity between peaks fell below the ANZECC guideline by at the beginning of June, around six months after the fires began, the large peaks continued throughout the year. Cudgewa Creek also experienced two prolonged anoxic periods that lasted for up to nine continuous days with DO falling as low as 0.6 ppm. Around 40 km downstream of where these creeks join the Murray River (Murray River at Jingellic; Figure 3), large peaks in discharge and turbidity were also observed throughout the year. Although, the mean turbidity between peaks fell below the ANZECC guideline in early April, around four months after the fires began. The largest peak in turbidity (4210 NTU) also coincided with a steep drop in DO where there was no dissolved oxygen (0.0 ppm) for a period of 1.5 hours. Unsurprisingly, this section of the upper Murray River experienced several aquatic mortality events where thousands of animals, including fish, crustaceans, and platypus were affected (Table 1 and Figure 1). These events were observed in late January 2020, before the water quality loggers were installed and likely mark the first large rainfall events in the area following the beginning of the fires.

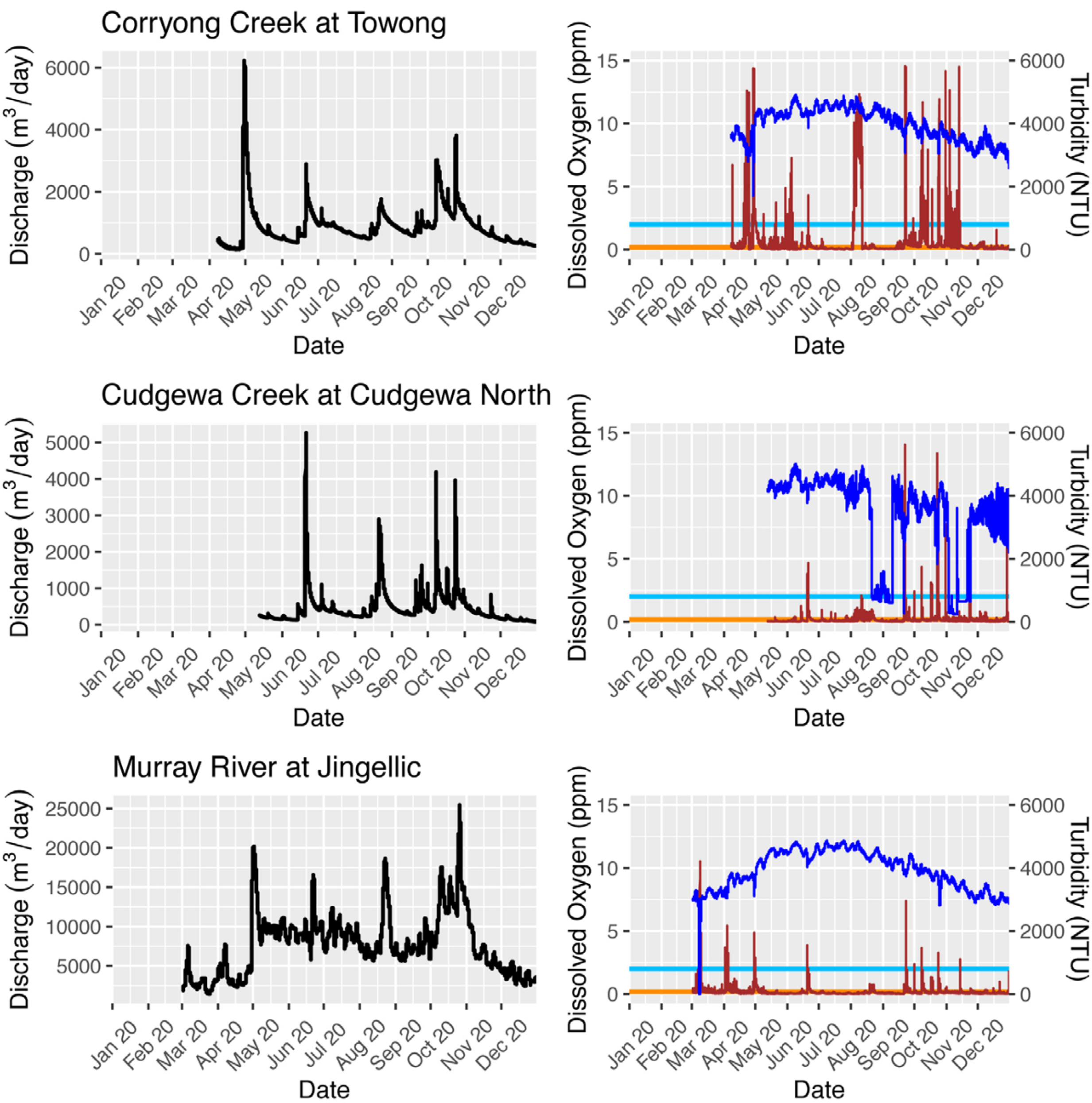

Figure 3. Stream discharge (black), dissolved oxygen (blue) and turbidity (brown) readings at three sites within the Upper Murray-Walwa Fire area in the year following the beginning of those fires (January 1st to December 31st 2020).

Orange line = guideline turbidity value for aquatic ecosystems (50 NTU) from the Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 (ANZECC); Light blue line = dissolved oxygen threshold for anoxic conditions (2.0 ppm). Note that loggers were placed at varying times following the fires.

While pre-fire and/or continuous water quality data was not available from many fire affected catchments, monthly water quality sampling at some sites provides an indication of the extent of the impacts. Table 2 summarises maximum turbidity and minimum dissolved oxygen (DO) concentrations in seven streams with various catchment sizes (252–13420 km^2) in eastern Victoria, before and after they were burnt during the 2019/20 bushfires. Maximum turbidity measured during the year prior to the fires ranged between 5 and 30 NTU (mean 18.6), while post fire turbidity ranged between 44 and 5833 NTU (mean 2218). Minimum DO concentrations ranged between 4.0 and 9.1 ppm (mean 7.3) prior to the fires, while post fire DO ranged between 0 and 8.0 ppm (mean 4.1). For both turbidity and DO, the largest peaks and troughs in concentration were captured by continuous logging datasets.

Table 2. Maximum turbidity and minimum dissolved oxygen data from streams in catchments burnt by bushfire. Recordings were either taken once a month in the year prior to and following the 2019/20 bushfires, or continuously logged (marked with a 'C').

Location	Latitude	Longitude	Catchment size (km^2)	Pre-fire maximum turbidity (NTU)	Post-fire maximum turbidity (NTU)	Pre-fire minimum DO (NTU)	Post-fire minimum DO (ppm)
Murray River at Jingellic	-35.93141	147.7115	6527	30	4210 (C)	8.4	0.0 (C)
Tambo River at Swifts Creek	-37.26878	147.72882	943	7	44	8.1	7.9
Tambo River at Battens Landing	-37.75731	147.84912	2781	36 (C)	1963 (C)	4.0 (C)	0.25 (C)
Rodger River at Jacksons Crossing	-37.41016	148.35987	447	5	95	7.2	8.0
Snowy River at Jarrahmond	-37.70739	148.45095	13420	12	771	8.3	7.5
Genoa River Gorge	-37.41577	149.52038	837	42	2610 (C)	6.25	0.0 (C)
Nariel Creek at Upper Nariel	-36.44500	147.82949	252	5	5833 (C)	9.1	5.3 (C)

Periods of heightened turbidity may occur briefly (minutes to hours) during stormflow events or they may persist beyond initial event timescales (days to months) (e.g. Lyon and O'Connor 2008). The extent and duration of subsequent water quality impacts will depend upon the amount of sediment in storage, the magnitude and frequency of post-fire flow events required to re-suspend and transport this material, as well as new sediment inputs from erosion. The input of new sediment is expected to decrease over time as the ash load is depleted and vegetation recovers to the point where it can stabilise catchment slopes. Based on the data collected here, the extent and intensity of the fires and subsequent heightened summer rainfall has led to extreme and prolonged impacts (over 12 months) on water quality that is likely responsible for the observed mass mortality of aquatic fauna.

Due to the remote nature of many of the impacted catchments, it seems likely that such mortality events were far more widespread but were not observed. Furthermore, small fish species and invertebrates are less apparent following a mortality event and thus are not well accounted for when using mortality events as an indicator of impact. For instance, post-fire monitoring efforts focussed on the Yalmy Galaxias (*Galaxias* sp. nov. 'Yalmy'), recorded a drop in CPUE from 12 fish/100m (average over 5 years) pre-fire to no fish/100 m post-fire. Similarly, post-fire monitoring in the upper Cotter River (ACT) recorded declines of ~80% in the abundance of Rainbow Trout and Two-spined Blackfish (Mark Lintermans, unpublished data). Of note, no fish kills associated with the fires were reported later than mid-February 2020, although the water quality and physical habitat conditions remained highly degraded at least until the end of the year. This may suggest that the initial shock of the rapid change in conditions can lead to instant, mass mortality, although some animals may relocate to less impacted reaches where they can persist until conditions improve. However, they would be impacted by the chronic effects of increased turbidity. Lyon and O'Connor (2008) found the fish community in the fire-impacted Ovens and Buckland rivers, following a large 2003 bushfire in Victoria, had begun to recover after 24 months. The results here suggest that conditions were returning post-fire levels around a similar period.

3. Coordination and decision making

In response to the threat the 2019/20 bushfires posed to aquatic animals, governmental organisations allocated roles and formed groups tasked with coordinating and conducting the conservation response. Here we summarise the chain of responsibility that was followed during and immediately after the fires in each jurisdiction that ultimately facilitated the aquatic conservation response, and indeed the broader biodiversity response, to the bushfires (Figure 4). Groups and roles responsible for other facets of the bushfire response are not included. Also, as Queensland was not as heavily impacted by the fires as other jurisdiction and their conservation response was accordingly smaller, they are not discussed here. Their aquatic conservation response was the act of individuals working within the Department of Environment and Science and as contractors. Prior to the fires, NSW was experiencing a drought emergency and the Murray–Darling Basin Native Fish Drought Response Committee had already been set up to coordinate the rescue of at-risk aquatic fauna, so this framework was extended to account for the threat of fire as well. In Victoria and the ACT the biodiversity conservation response was organised under each jurisdiction's existing emergency response framework which had a similar structure.

New South Wales

Group/title	Organisation/department	Role
NSW Murray–Darling Basin (MDB) Native Fish Drought/Fire Response Coordination Committee	NSW Department of Primary Industries (DPI) (Fisheries Division) Executive	Guide the delivery of emergency actions and allocate funding
NSW MDB Native Fish Drought/Fire Response Coordinator	NSW DPI (Fisheries)	Guide the delivery of emergency actions
Regional Technical Advisory Groups	NSW Government reps. and regional experts	Assessment of threatened species and recommendations for action
NSW DPI Fisheries Teams and contractors	NSW DPI (Fisheries)	On ground coordination of conservation actions

Victoria

Group/title	Organisation/department	Role
State Controller Wildlife	Victorian Government	Guide the delivery of emergency actions
Department of Environment, Land, Water and Planning (DELWP)	DELWP Executive (mostly Biodiversity Division)	Guide the delivery of emergency actions and allocate funding
Bushfire Rapid Risk Assessment Teams	DELWP reps. and regional experts	Assessment of threatened species and recommendations for action
Arthur Rylah Institute	DELWP (Biodiversity)	On ground coordination of conservation actions

Australian Capital Territory

Group/title	Organisation/department	Role
Environment, Planning and Sustainable Development Directorate (EPSDD)	EPSDD Executive	Guide the delivery of emergency actions and allocate funding
Bushfire Rapid Risk Assessment Teams	ACT Government reps. and regional experts	Assessment of threatened species and recommendations for action
Parks and Conservation Service and Conservation Research	EPSDD	On ground coordination of conservation actions

Figure 4. Flow chart summarising the chain of responsibility in each jurisdiction during and immediately after the fires leading to the aquatic conservation response.

At the executive level, members of the state government departments responsible for environmental management took on a range of emergency roles with the goal of guiding the delivery of emergency actions and allocated funding to support the range of measures used to manage risks to biodiversity. This encompassed the spectrum of emergency needs including preparedness, prevention, response and recovery. Furthermore, in Victoria and NSW an individual was allocated to an overall management / coordination role who was embedded in or worked closely with the executive group overseeing the biodiversity response.

At the next level of decision making, technical advisory groups were formed that included biodiversity managers and species experts from within and outside of government who assessed the impact or threat to species by the fires, prioritised at risk species, and planned the specifics biodiversity response and recovery actions. In Victoria and the ACT, these were Rapid Risk Assessment Teams (RRATs), while in NSW there were less formal Technical Advisory Groups formed for different regions withing the State. In some cases, these teams/groups were informed more heavily by a particular organisation. For instance, in Victoria, the knowledge of the threatened aquatic fauna and fire management options was predominantly found within ARI who have extensive post-fire emergency management expertise extending back to 2006 (Raadik 2007, Raadik and Clunie 2007, Raadik et al. 2019, Ayres et al. 2012, Raadik and Nicol 2012, 2015, Raadik 2018, Stoessel et al. 2021).

Primarily, impacts were assessed using the proportions of actual or modelled habitat for each species that were within the fire extent (> 30%). This information was periodically updated as revised fire extent and intensity mapping and information from the on-ground species reconnaissance become available. Existing data and expert opinion on the vulnerability of species to fire impacts was also used to prioritise responses. Further to this, at the Federal level, the Minister for the Environment asked the Threatened Species Commissioner, Dr Sally Box, to convene an Expert Panel to assist in prioritising recovery actions for native species, among other important assets, affected by the 2019/20 extreme fire events. The resulting Wildlife and Threatened Species Bushfire Recovery Expert Panel was established and provided advice on critical interventions required to support the immediate survival of priority animals, plants and ecological communities. The Panel helped assess the scale and impact of the bushfires on the environment and identified priority taxa that have more than 10% of their known and likely distribution in fire-affected areas (Legge et al. 2020). The prioritisation included consideration of a species physical, behavioural and ecological attributes that influence the chance of being killed directly by fire; some physical, behavioural and ecological attributes of species affect the chance of survival in the weeks and months following the fire, and the capacity of populations to recover after a fire event. This species prioritisation assisted with the prioritisation of recovery efforts at both State and national scales and informed the development of a strategy for building populations and resilience of native plants and animals.

The recommendations of these various technical advisory groups were assessed at the executive level and funding was then allocated to environmental science groups or individuals who executed the conservation plans. While most of these recommendations were acted upon, some conservation interventions could not proceed due to access issues caused by the fires or were not funded due to the finite amount of resources available and their perceived lower priority level.

Those conducting the on-ground response followed their various institutional guidelines, some of which were developed adaptively to address the unique nature of the threat. These groups were largely responsible for coordinating conservation actions in active firegrounds, working closely with Incident Management Teams (e.g. Planning Officers and Operations Officers) who played a critical role in providing access and logistical support. Often on State and National Parks land, and focussed on threatened species, so there were several requirements that needed to be met before the work could commence. In each jurisdiction this included gaining:

- A fishery permit and threatened species permit to work on threatened fish;
- A translocation permit to move species and hold them in captivity;
- Training to enter a fireground (e.g. fire ground safety training [online course], chainsaw licence, 4WD training, hazardous tree training [online course]);
- Necessary Personal Protective Equipment (PPE) to enter the fireground;
- Permission to enter the fireground from the relevant Incident Controller;
- Permission to enter National Parks or private land as necessary; and
- Permission from Police to enter a crime scene if there were fatalities within the fireground.

While fisheries and threatened species permits were already held by the people and organisations conducting the aquatic conservation response, and likely always will be, most other requirements needed to be met (i.e. training done, permits sought) during the planning of conservation efforts.

4. Aquatic animal recovery actions during and following the fires

The priority conservation actions recommended for threatened species and populations largely aimed to salvage species and populations from threatened habitats and hold them in temporary captivity until conditions improved and they could be returned. While other activities were taken to aid in freshwater conservation, such as sediment control and impact monitoring, captive management was the main tool used to prevent the extinction of species and populations. As such we focus on these projects here. As discussed in Section 4, not all species impacted by the fires were included in the conservation response due to finite funding and the nature of the prioritisation stage. The species which missed out tended to be those with broad distributions which meant that a smaller percentage of their habitat was burnt, but that isn't to say that important populations were not threatened. Below we provide a brief description of each of the captive-management projects conducted in south-eastern Australia in response to the 2019/20 bushfires, and summarise the target species, their conservation status and distribution burnt in Table 3.

4.1 New South Wales

4.1.1 Eastern Freshwater Cod (*Maccullochella ikei*)

The Eastern Freshwater Cod is a large (max. 665 mm Tail Length [TL]) fish known from the Clarence River and Richmond River catchments (Butler 2019). Approximately 47% of its range was burnt during the 2019/20 fire season. Two of the four largest populations of the species in the Mann and Nymboida rivers were considered under threat due to the significant ash load on the catchments hills and slopes that would have been washed into the streams following the next significant rainfall event. In response to this threat, 98 Eastern Freshwater Cod were salvaged in December 2019. The majority were held in two storage dams as insurance populations. The remainder were taken to NSW DPI Grafton Fisheries Centre to support a captive breeding program.

4.1.2 Oxleyan Pygmy Perch (*Nannoperca oxleyana*)

Oxleyan Pygmy Perch is a small species of fish (max. 80 mm TL) endemic to the coastal region of eastern Australia, from northern NSW to south-eastern Queensland. They are patchily distributed within swamps, streams and lakes of lowland, coastal wallum heath within their range (Butler et al. 2019). Approximately 71% of the species' range was burnt, predominantly in the Clarence River catchment. Habitat within the catchment was affected by debris/sediment flow events from heavy rainfall following the bushfires prompting a captive management program. A total of 252 fish were salvaged in December 2019 and held at the NSW DPI Grafton Fisheries Centre as an insurance population.

4.1.3 Stocky Galaxias (*Galaxias tantangara*)

The Stocky Galaxias is a small species of fish (max. 114 mm TL) that only occurs in the headwaters of Tantangara Creek in Kosciusko National Park. It is restricted to a 4 km stretch of the creek above a waterfall which prevents upstream movement of predatory trout that would otherwise eliminate them (Lintermans and Allan 2019). Approximately 70% of Stocky Galaxias habitat was burnt by bushfires in January 2020. High intensity rainfall was predicted for early February 2020 which was expected to negatively impact water quality through ash run-off, which initiated a salvage and captive management program. One 142 Stocky Galaxias were rescued from the creek after fire entered the subcatchment and one day before predicted heavy rain. Rescued fish transported to NSW DPI Gaden Fisheries Centre, Jindabyne.

4.1.4 Short-tail Galaxias (*Galaxias brevissimus*)

The Short-tail Galaxias is a small species of fish (max. 95 mm TL) known only from the upper reaches of the Tuross River system in southern, coastal NSW. Specifically, it is found as two isolated sub-populations in Guinea Creek, and its tributary Jibolaro Creek, along with Bumberry Creek (Lintermans and Raadik 2019). While not yet conservation listed in NSW, it is listed as Critically Endangered on the IUCN Red List. A rescue was mounted as the Bumberry Creek catchment was burning, and fire was very close to Jibolaro/Guinea Ck sub-population. Access to the Bumberry Creek site was not possible during the fire and subsequent heavy rain following the fire, meant this sub-population had already been impacted. By the end of the fire season, 82% of the species' habitat was burned. Thirty-seven fish were rescued from the Guinea Creek/Jibolaro Creek sub-population. The rescued fish were transported to NSW DPI Gaden Fisheries Centre, Jindabyne, for temporary captive management.

4.1.5 Macquarie Perch (*Macquaria australasica*)

The Macquarie Perch is a moderately large species of fish (max. 550 mm TL) with a preference for cool, clear freshwater habitats and slow-flowing deep rocky pools. It is known from scattered localities in the cool upper reaches of the MDB in NSW as well as Victoria and the ACT (Lintermans et al. 2019a). Mannus Creek, which is home to an important MDB population, was burnt between December 2019 and January 2020. Heavy rainfall was predicted to occur in February, so a captive management program was initiated. Nine fish were salvaged from the creek prior to the debris/sediment flow event and were held at the NSW DPI Narrandera Fisheries Centre.

4.1.6 Olive Perchlet (*Ambassis agassizii*)

The Olive Perchlet is a small species of fish (max. 86 mm TL) that occurs from Rockhampton (Queensland) to Lake Hiawatha (NSW), with a translocated population in Swan Reach (South Australia). Historically distributed throughout the MDB, the species now occurs in fragmented populations in NSW and Queensland regions of the basin. The MDB populations represent a genetic lineage that is distinct to east-coast populations (Raadik and Unmack 2019).

Olive Perchlet habitat within the Border Rivers area of the MDB was burnt by fires in November and December 2019. Debris/sediment flow events were witnessed in Tenterfield Creek in December 2019 after heavy rainfall which threatened the Olive Perchlet population downstream. This region was already being impacted by prolonged drought. In response to the threats posed by the drought and debris/sediment flow events following the fires, 700 Olive Perchlet were salvaged from the region between October 2019 and February 2020. These fish were taken to the NSW DPI Grafton Fisheries Centre to set up a captive breeding insurance population for re-release once the drought breaks.

4.1.7 Southern Purple Spotted Gudgeon (*Mogurnda adspersa*)

The Southern Purple Spotted Gudgeon is a small species of fish (max. 130 mm TL) that occurs in coastal drainages from the Pascoe River (Queensland) to the Clarence River (NSW), and inland MDB drainages from the Macquarie River (NSW) to the Onkaparinga River (South Australia). In NSW sections of the MDB, the species is confined to small remnant populations in the Macquarie, Gwydir and Border Rivers catchments and a self-sustaining population from captive-bred fish in the Castlereagh Catchment. On the east coast of NSW they occur in catchments north of the Clarence River. The MBD and east coast populations represent two distinct genetic lineages, and populations within the MDB have experience substantial decline.

Southern Purple Spotted Gudgeon habitats within the Tenterfield/Border Rivers areas of the MDB were experiencing drought conditions before being impacted by fires in the Tenterfield Creek area between November and December 2019. Heavy rainfall was predicted in the area which was expected to cause debris/sediment flow events that would threaten Southern Purple Spotted Gudgeon within Tenterfield Creek and further downstream. In response to these threats, salvage efforts were made in December 2019. However, these efforts came after the rainfall and initial debris flows, and only one fish was caught during the operation. This fish was rescued and taken to the NSW DPI Fisheries Grafton Fisheries Centre where it was housed with Southern Purple Spotted Gudgeon taken from the Gwydir river catchment as part of drought rescue operations.

4.2 Victoria

4.2.1 Macquarie Perch (*Macquaria australasica*)

A brief description of this fish species and its habitat has been provided previously in section 4.1.5. In Victoria, as elsewhere, the species has undergone a considerable decline in range and abundance. The species, however, remains present in isolated sites in the Goulburn, Broken, Ovens and Mitta Mitta catchments. The 2019/20 bushfires burnt large areas of the Buffalo River catchment (a tributary of the Ovens River), and substantial rainfall was predicted for early 2020 that threatened an important Macquarie Perch population. So, to guard the population against major decline 15 Macquarie Perch were captured from fire affected sites and translocated to nearby unimpacted rivers, while another 24 were transferred to the Victorian Fisheries Authority hatchery at Snobs Creek for temporary captive management.

4.2.2 Murray Cod (*Maccullochella peelii*)

The Murray Cod is a large species of fish (max. 1800 mm TL) that is endemic to all major catchments within the MDB except for the Wimmera River (Victoria) where translocated populations occur (Gilligan et al. 2019). However, it has experience dramatic declines in abundance predominantly due to habitat alteration and overfishing. During the Macquarie Perch rescue on the Buffalo River (described above), 20 fish were translocated further upstream from fire affected sites in the Buffalo River to aid in the recovery of the species in this region.

4.2.3 Dargo Galaxias (*Galaxias mungadhan*)

The Dargo Galaxias is a small species of fish (max. 110 mm TL) that is only known from the headwaters of Lightbound Creek, a tributary of the Dargo River, in the East Gippsland region of Victoria (Raadik 2019a). Approximately 70% of the species' distribution was burnt in the 2019/20 bushfires. Substantial rainfall occurred in late January–early February 2020, after the fires, which threatened a large proportion of the species' range. To guard the species against dramatic population decline, 200 fish were salvaged and translocated to an aquarium facility at ARI for temporary captive management in February 2020.

4.2.4 East Gippsland Galaxias (*Galaxias aequipinnis*)

The East Gippsland Galaxias is a small species of fish (max. 90 mm TL) endemic to the Arte River system, a tributary of the Goolengook River, Bemm River catchment, in the East Gippsland region of Victoria, at an elevational range of 250–390 m above sea level (Raadik 2019b). The entire distribution of this species was burnt in the 2019/20 bushfires, then substantial rainfall occurred in the region in late January–early February 2020 that threatened the species with extinction. To guard the species against extinction 100 fish were salvaged and translocated to an aquarium facility at ARI for temporary captive management in February 2020.

4.2.5 Yalmy Galaxias (*Galaxias* sp. nov. 'Yalmy')

The Yalmy Galaxias is a small (max. 110 mm TL), newly discovered species of fish that is restricted to 9 km of stream in the mid-reaches of the Yalmy River, Serpentine Creek, and the lower Rodger River, Victoria, at an elevational range of 140–250 m above sea level (Raadik 2019c). The entire distribution of this species was burnt in the 2019/20 bushfires and the region received heavy rainfall before salvage efforts could be made. When the salvage was conducted the stream habitat was catastrophically impacted and only seven fish could be caught. They were salvaged and translocated to an aquarium facility at ARI for temporary captive management in February 2020.

4.2.6 McDowall's Galaxias (*Galaxias mcdowalli*)

The McDowall's Galaxias is a small species of fish (max. 90 mm TL) that is restricted to a small stream in the headwaters of the upper Rodger River, a tributary of the Snowy River, in the East Gippsland region of Victoria (Raadik 2019d). The entire distribution of this species was burnt in the 2019/20 bushfires, then substantial rainfall occurred in the region in late January–early February 2020 that threatened the species with extinction. To guard the species against extinction 100 fish were salvaged and translocated to an aquarium facility at ARI for temporary captive management in February 2020.

4.2.7 Cann Galaxias (*Galaxias* sp. nov. 'Cann')

The Cann Galaxias is a small (max. 90 mm TL), newly discovered species of fish that is restricted to small stream sections in three tributaries of the Cann River, in the East Gippsland region of Victoria (Raadik, T.A., unpublished data). The entire distribution of this species was burnt in the 2019/20 bushfires, then substantial rainfall began in the region in late January–early February 2020 that threatened the species with extinction. To guard the species against extinction 25 fish were salvaged and translocated to an aquarium facility at ARI for temporary captive management in February 2020

4.2.8 River Blackfish – South-east Victoria (*Gadopsis* sp. nov. 'SEV')

The River Blackfish 'SEV' is a cryptic candidate species of fish within the *Gadopsis marmoratus* species complex that occurs in streams south of the Great Dividing Range in south-eastern Victoria (Hammer et al. 2014). It is moderately large, growing up to 600 mm TL. Approximately 80% of this species' distribution was burnt in the 2019/20 bushfires, then substantial rainfall occurred in the region in late January–early February 2020 that threatened a large proportion its habitat. To guard the species from dramatic decline, 11 fish were salvaged and translocated to an aquarium facility at ARI for temporary captive management in February 2020.

4.2.9 East Gippsland Spiny Crayfish (*Euastacus bidawalus*)

The distribution of the East Gippsland Spiny Crayfish encompasses an area from near Mount Imlay (NSW) to Lind National Park near Cann River (Victoria), a distance of approximately 90 km. It is a highland species known from elevations between 150 and 400 m above sea level. The maximum recorded Occipital Carapace Length (OCL) is 48 mm (Morgan 1986). The entire distribution of this species was burnt in the 2019/20 bushfires, then substantial rainfall began in the region in late January–early February 2020 that threatened the species with extinction. To guard the species against extinction 41 crayfish were salvaged and translocated to an aquarium facility at ARI for temporary captive management in February 2020.

4.2.10 Orbost Spiny Crayfish (*Euastacus diversus*)

The Orbost Spiny Crayfish has one of the most restricted distributions of all *Euastacus* species, having been found at only seven locations on and around the Errinundra Plateau in East Gippsland (Coughran et al. 2015). Most of these populations occur in the headwaters of the Brodribb River, although one occurs in Yandown Creek in the headwaters of the Queensborough River. The maximum recorded size of the species is 45 mm OCL. Approximately 95% of the species' range was burnt in the 2019/20 bushfires, then substantial rainfall occurred in the region in late January–early February 2020 that threatened the species with dramatic population decline. To guard against this impact 30 crayfish were salvaged and translocated to an aquarium facility at ARI for temporary captive management in February 2020.

4.2.11 Arte Spiny Crayfish (*Euastacus* sp. nov. 'Arte')

The Arte Spiny Crayfish is found in the upper reaches of the Arte River in East Gippsland (McCormack, R.B. and Raadik, T.A., unpublished data). The maximum recorded size of the species is 40 mm OCL. The entire distribution of this species was burnt in the 2019/20 bushfires, and the area received heavy rainfall before salvage efforts could be made. During the salvage efforts, only three crayfish could be found at the target locations that were heavily impacted by debris/sediment flows. These animals were salvaged and translocated to an aquarium facility at ARI for temporary captive management in February 2020.

4.2.12 Variable Spiny Crayfish (*Euastacus yanga*)

The distribution of the Variable Spiny Crayfish extends from around Robertson and Bundanoon (NSW) about 400 km south to Genoa (Victoria) (Moran 1997). The lowland species is found in foothills and lowland areas. The maximum recorded size is 61 mm OCL. The entire distribution of this species was burnt in the 2019/20 bushfires, then substantial rainfall began in the region in late January–early February 2020 that threatened the species with extinction. To guard the species against extinction 15 crayfish were translocated to an aquarium facility at ARI for temporary captive management in February 2020.

4.2.13 Depressed Freshwater Mussel (*Hyridella depressa*)

The Depressed Freshwater Mussel is found in coastal rivers and streams southeast Queensland, NSW (although absent from the Hunter and Shoalhaven Rivers) and eastern Victoria (Walker et al. 2014). It has been recorded up to 80 mm in length. The entire Victorian distribution of this species was burnt in the 2019/20 bushfires, then substantial rainfall began in the region in late January–early February 2020 that threatened the Victorian populations. To guard the species against dramatic population decline, 106 individuals were salvaged and translocated to an aquarium facility at ARI for temporary captive management in February 2020.

4.2.14 Glenelg Freshwater Mussel (*Hyridella glenelgensis*)

The Glenelg Freshwater Mussel is a small species (max. 51 mm long) that is endemic to the Glenelg River in western Victoria. The species was historically widespread in the catchment but has undergone significant population decline and is now restricted to a single reach of the lower Crawford River near the town of Dartmoor. A large proportion of the catchment upstream of this population was burnt in the bushfires experienced in western Victoria in 2020 and rainfall was predicted in February 2020. So, to guard the species against extinction 28 individuals were salvaged and translocated to an aquarium facility at ARI in February 2020 for temporary captive management.

4.3 Queensland

4.3.1 Mountain Galaxias (*Galaxias olidus*)

The Mountain Galaxias is a small (max. 130 mm TL), widespread species of fish associated with upland streams in the eastern and southern MDB and has a relatively small distribution in Queensland, which marks its northern extent (Raadik 2014). Spring Creek, in the upper Condamine River catchment, is an important drought refuge that holds one of the few Mountain Galaxias populations in Queensland. The creek was being impacted by drought and was further threatened by bushfires in region. So, 150 individuals were salvaged and translocated to Jardini, an aquaculture facility in Brisbane, for temporary captive management in February 2020.

4.3.2 River Blackfish (*Gadopsis marmoratus*)

The River Blackfish is a medium sized (max. 250 mm TL) species of fish that is endemic to the MDB. Most of its distribution is in Victoria and NSW, although a small northern population occurs in southern Queensland which represents a discrete genetic subunit (Hammer et al. 2014). Spring Creek, in the upper Condamine River catchment, is an important drought refuge for this northern population. The creek was being impacted by drought and was further threatened by bushfires in region, so 50 individuals were translocated to Jardini, an aquaculture facility in Brisbane, for temporary captive management in February 2020.

4.3.3 Lamington Spiny Crayfish (*Euastacus sulcatus*)

The Lamington Spiny Crayfish is an upland species that reaches 60 mm OCL and occupies a cold-water niche in forested upland streams in south-eastern Queensland and north-eastern NSW (Morgan 1997). Spring Creek, in the upper Condamine River catchment, represents an important drought refuge for this species, but was going dry towards the end of 2019. As an insurance policy against drought, and then the potential impact of local bushfires, 50 individuals were translocated to Jardini, an aquaculture facility in Brisbane, for temporary captive management in June 2020.

4.4 Australian Capital Territory

No captive management or rescue programs were undertaken. Funding was unsuccessfully sought to conduct captive management of a threatened population of Two-spined Blackfish.

Table 3. Priority post-fire affected species for which salvage efforts were conducted and the percentage of their range burnt in the 2019/20 bushfires.

The asterisk (*) denotes a listing that is currently being finalised. Species prioritisation was undertaken by various technical advisory groups in each jurisdiction as discussed in Section 5. ASFB = Australian Society for Fish Biology, MDB = Murray–Darling Basin.

Common name	Scientific name	State listing	EPBC Act	IUCN Red List	ASFB listing	Range burnt in respective jurisdiction (%)
New South Wales						
Eastern Freshwater Cod	*Maccullochella ikei*	E	E	E	E	47
Oxleyan Pygmy Perch	*Nannoperca oxleyana*	E	*	E	E	71
Stocky Galaxias	*Galaxias tantangara*	CE	CE	CE	CE	70
Short-tail Galaxias	*Galaxias brevissimus*		*	E	CE	82
Macquarie perch	*Macquaria australasica*	E	E	V	E	Mannus Creek pop.
Olive Perchlet (MDB)	*Ambassis agassizii*	E (MDB pop.)	Not listed	LC	Not listed	Dumaresq-Macintyre pop.
Purple Spotted Gudgeon (MDB)	*Mogurnda adspersa*	E	Not listed	LC	Not listed	Tenterfield River pop.
Victoria						
Macquarie Perch	*Macquaria australasica*	L	E	E	E	Buffalo River pop.
Murray Cod	*Maccullochella peelii*	L	V	LC	V	Buffalo River pop.
Dargo Galaxias	*Galaxias mungadhan*	L	*	CE	CE	70
East Gippsland Galaxias	*Galaxias aequipinnis*	L	*	CE	CE	100
McDowall's Galaxias	*Galaxias mcdowalli*	L	*	CE	CE	100
Cann Galaxias	*Galaxias* sp. nov. 'Cann'	Not listed	Not listed	Not listed	Not listed	100
Yalmy Galaxias	*Galaxias* sp. nov. 'Yalmy'	Not listed	*	CE	CE	100
River Blackfish–South-east Victoria	*Gadopsis* sp. nov. 'SEV'	Not listed	Not listed		Not listed	60
East Gippsland Spiny Crayfish	*Euastacus bidawalus*					100
Orbost Spiny Crayfish	*Euastacus diversus*	L		E		95
Arte Spiny Crayfish	*Euastacus* sp. nov. 'Arte'					100
Variable Spiny Crayfish	*Euastacus yanga*			LC		100
Depressed Freshwater Mussel	*Hyridella depressa*					100
Glenelg Freshwater Mussel	*Hyridella glenelgensis*	L	CE	CE		90
Queensland						
Mountain Galaxias	*Galaxias olidus*				Not listed	Stoney Creek pop.
River Blackfish	*Gadopsis marmoratus*			LC	Not listed	Stoney Creek pop.
Lamington Spiny Crayfish	*Euastacus sulcatus*			V		Stoney Creek pop.

5. What did and didn't work during the conservation response

Before beginning this section, it is important to note that in emergencies such as bushfires, many dedicated and capable people step up and take responsibility for dealing with the emergency on behalf of their community; this is no small matter. Those people who make decisions and act in good faith under extenuating circumstances do not have the same luxury of time afforded to those of us undertaking this review. Their decisions and actions are often progressed in difficult, unfamiliar, and changing situations, often without the benefit of full situational awareness. As such, any deficiencies observed should not be viewed through the lens of individual fault and blame. It is reasonable to accept that decision makers and action takers in an emergency do so to the best of their abilities and they should expect that their professional reputation and self-worth are not at risk if their actions do not go precisely to plan. The fire extent, both spatial (10 million hectares Australia wide) and temporal (fires burned from July 2019 to May 2020), was unprecedented. There were no established systems to deal with such an extended and prolonged threat. Biodiversity responses were often a substantially lower priority for those controlling fire grounds or fire-fighting resources than those involving human safety and welfare. Deficiencies in a response or identified areas of improvement should be examined in the context of improving the emergency response. There will always be opportunities for improvement facilitated by open and honest dialogue about how we can do better. We applaud the openness of those that we interviewed and their commitment to aquatic conservation and continuous improvement in their work.

5.1 Governance and decision making

There was consensus across those interviewed that the activation of the various elements of the emergency response and relevant emergency management components worked and delivered the required effect. Individual agencies identified that their internal mechanisms were also reviewed, activated, and implemented as required. From the perspective of those conducting the biodiversity on-ground response, there were clear lines of communication between them and the upper organisational levels, or at least interdepartmental staff worked collaboratively to quickly establish them. Also, the risk assessment processes (e.g. RRATs) were inclusive, worked as fast as could be expected, and were effective in identifying which recovery efforts should be made for best effect. All respondents acknowledged the collaborative approach within organisations provided a constructive environment for matters to be resolved as and when they arose.

However, a recurring response was that once the decision had been made to conduct a given rescue program, funding was slow to be approved and released to those that needed to conduct the work. The rescue efforts needed to be conducted rapidly; either during the fire emergency itself or following the bushfires when high rainfall events threatened to cause mass mortality among the threatened species. So, even small delays (days to weeks) were potentially very costly. These delays were typically in the range of one month, but in one case in Queensland it took up to 12 months to receive funding to assess a fire-affected population of a threatened species to see whether they required emergency intervention. In such timeframes the threatened species were impacted by several debris/sediment flows, and in at least one case in Victoria the rescue attempt came after the stream environment had been catastrophically impacted and only seven fish could be captured. As one respondent put it "It is also critical that there is an understanding within the upper levels of management how critical it is to act in a timely manner and how significant the consequences can be if we don't." The delays prompted various groups to act before emergency funding arrived, drawing funding from novel sources within their own institutions to conduct the field work in a timelier manner and taking on the risk that their expenses would not be covered by the emergency funding.

This issue was less prominent in NSW where emergency funding had already been allocated to NSW DPI to support native fish through the drought they were experiencing, and some of those funds were made available for the conservation response to the fires, though was not directed to all target species due to competing needs. This allowed for rapid, post-fire surveys to better assess the threat to target species in some cases, which helped when deciding where to enact salvage and captive management efforts. Furthermore, salvage and captive management efforts could occur within the necessary timeframe. This emergency funding, no doubt, increased the speed of the emergency response, but it was only available due to happenstance and did not cover all target species.

Recommendation 1: Create a dedicated emergency fund in each jurisdiction that can be immediately drawn upon to conduct time-critical conservation activities when responding to emergencies such as drought and bushfire. Adequate funding for extended captive maintenance (up to a year) also needs to be identified and secured.

Another issue raised was that the separation of management responsibilities and legislation in some jurisdictions presented a significant problem when trying to coordinate the fire emergency response, and subsequent recovery actions. For instance, in NSW there are two separate government departments that focus on terrestrial (Department of Planning, Industry and Environment [DPIE]) and aquatic (Department of Primary Industries–Fisheries) ecosystems and fauna that were both vying for the same conservation funding. DPIE also manages semi-aquatic animals such as frogs, Platypus, and Rakali, while NSW DPI fisheries manage fully aquatic animals such as fish, mussels, and crayfish. In this instance, when the Federal Government requested priority funding bids related to the fires, the request went to DPIE, but not DPI Fisheries, so very little funding was gained for the conservation of fully aquatic fauna. The division of responsibility between different departments and allocation of funding through functional agreements was not seen as being conducive to the best outcomes for wildlife or conservation in general. This lies in contrast to Victoria, where terrestrial and aquatic conservation is managed under the Department of Environment, Land, Water and Planning alone and prioritisation of actions and allocation of funding was handled as part of the same process (i.e. the RRATs and associated collaborative workshops). Furthermore, this prioritisation process was admirably collaborative and inclusive, involving group discussions between a wide range of government and non-government experts. So, even if the responsibility for the management of threatened taxa was spread across departments, this would be inconsequential if decision-making was made as part of a central, collaborative process.

Recommendation 2: Conservation responses to catastrophes like fires, floods and droughts should be centrally managed and coordinated.

The planning stages of the on-ground fish rescue response was effective by all reports, although there were several factors that impacted on the efficiency of these operations. Positively, efforts were made to reduce any delay in conducting the work. For instance, application for translocation permits must be assessed by a translocation committee and can be a lengthy process. However, these applications were expedited under the circumstances. Furthermore, training to enter the fireground (e.g. fire ground safety and hazardous tree training) could be conducted in online modules and was not arduous. The appropriate PPE was able to be sourced locally and the cost wasn't prohibitive. However, a point was raised that chainsaw licences and official 4WD training was not held by all staff involved. This could be overcome when untrained staff were accompanied by trained staff, but these qualifications can't be gained on short notice which raises a potential issue where aquatic conservation teams may not be able to enter the fireground. A situation like this occurred during the 2003 bushfires in Canberra, where there was a three month wait for chainsaw training due to the increased demand and limited availability of trainers and courses.

Recommendation 3: Taskforces/staff who are expected to take part in an emergency response should maintain the appropriate training so that delays in access to the fireground are reduced.

The matter of gaining permission to enter National Parks and the fireground, while navigated in all cases, was slowed down in some instances when the appropriate National Parks representative or Incident Controller, who could give permission, could not be identified. As one respondent said, "Understandably, the focus of fire control officers and incident teams was on human or asset safety during the fires in 2019/20. Finding out who in the fire incident control team was responsible was not straightforward and changing incident controllers (as people were rotated between fire incident teams or stood down for a break) meant that continuity of information was not seamless in some cases." A clearly defined process for gaining permission to enter these areas during a fire emergency would speed up the response time and likely improve the overall success of future rescues.

Recommendation 4: Develop a clearly defined process for gaining permission to enter National Parks and the fireground during bushfires to improve the response time of conservation teams.

The salvage and transportation of aquatic animals to aquaria for captive maintenance was effective in all cases, with the operations conducted without any major issues and resulting in very few animal deaths. However, some difficulties arose during captive maintenance that could be learned from. Many of these species, being rare and threatened, or recently described as species, had never been kept in captivity so there was a lack of prior experience in maintaining them. Consequently, some aquarium facilities were not prepared when some species started to display aggressive inter- and intra-species behaviour that led to substantial mortality. In the case of two galaxiid species, it became necessary to stock as few as one or two individuals in a tank to avoid the aggressive interactions, which required more aquaria than was available or could prepared at short notice.

In one instance where an aquarium that was not fit-for-purpose was used, the required biosecurity measures were not taken following the receipt of rescued fish as staff were not aware of those requirements. Therefore, the rescued fish could not be subsequently returned to the wild.

Furthermore, the captive maintenance programs continued for up to 15 months in cases where the fish were re-released (some were kept as brood stock for captive breeding programs). This is a considerable amount of time to care for hundreds of fish from multiple species that require daily care. In one case, funding for captive management of the animals ran out before the conditions at the collection site improved, so the animals could not be returned (as per the translocation permit rules). While these captive maintenance programs were led by highly qualified individuals, in Victoria the aquarium facilities used to care for all the small fish species are not permanent but are kept in readiness for such emergencies. The operation of the facilities is reliant on short-term funding in the event of an emergency. Only a small team of three staff, who pioneered captive management of freshwater fish in Victoria following the 2006 bushfires, are experienced in setting up the aquaculture facility and operating it at the standard necessary to ensure the success of such programs. Furthermore, they must do this while conducting their normal jobs. The ACT Government have a similar facility, albeit on a smaller scale, while the Queensland government do not have fit-for-purpose facilities in the south-east of the State and used a commercial aquarium facility instead.

This contrasts with NSW where full-time, government-run aquarium facilities exist at Narrandera and Grafton for conservation, scientific and recreational fishery purposes. Such permanent facilities ensure that a base level of qualified, dedicated staff is maintained, and ensure that there is sufficient aquarium capacity that is ready-to-go in the event of a large-scale and sudden emergency such as the 2019/20 bushfires. Also, as they are established facilities with permanent aquarium staff, operating on a long-term business model, the additional operational cost of sudden, prolonged (up to a year) maintenance of threatened species during an emergency would be less than for temporary aquarium setups. Regardless, additional funding would still be required to account for the additional staffing needs during large-scale emergencies.

In Victoria, the Snobs Creek Hatchery has significant capacity and experience in caring for large native fish of recreational significance and was used in the captive management of Macquarie Perch following the 2019/20 bushfires. Furthermore, a State Government funded native fish hatchery is being constructed in the town of Arcadia in northern Victoria that is proposed to have the capacity to breed small threatened species as well as large, recreationally significant species (VFA-Native-Fish-Hatchery-Artwork-Newsletter-Email (004).pdf). These facilities may be better suited to conduct long-term captive management of native fishes in the event of future emergencies, but agreements need to be put in place that they will support and assist, and efforts need to be taken to ensure the knowledge gained from previous efforts is transferred to the staff at those facilities so that they are adequately prepared.

Recommendation 5: Ensure agreements are put in place that identified fish hatcheries and aquariums will support and assist emergency captive management programs, which would include knowledge sharing and direct training of staff and commitment of resourcing in such circumstances.

Recommendation 6: Facilities for care of threatened native fishes impacted by drought and fire should be developed in Queensland.

The level of communication between conservation managers and fire controllers was not considered strong in most cases, and the perception was that this raised the risk of well-meaning firefighting activities having catastrophic impacts on freshwater environments. For instance, on Frazer Island (Queensland) saltwater was used to extinguish fires around the island's spring-fed freshwater systems where the conductivity (i.e. salt level) is close to zero. An assessment of the impact of these actions is yet to be conducted, but it has likely been detrimental to the local fauna. The use of fire retardants, that can poison aquatic fauna, within areas occupied by threatened species, and the transfer of invasive species between water bodies when water bombers draw their water from one location and drop it in another, were two further concerns. By all accounts, fire controllers positively responded when informed of these risks, but it appeared that this information was not readily available to them.

On this point, lessons learned regarding information flow and decision making during the 2019/20 fires helped inform the completion of a new web-based GIS decision-making tool (a Biodiversity Risk Layer) for Incident Management Team (IMT) decision makers to use in Victoria. The Biodiversity Risk Layer, available through the eMap portal, identifies biodiversity at-risk from an incident, provides advice on mitigating actions, and links to further information or key contacts. It presents a central information resource that can be continuously updated as knowledge improves, and management practices change. By making this information easily available to staff making critical decisions during an emergency, it facilitates a rapid, robust response, ensuring that priority actions are undertaken, and inadvertently damaging ones are not.

Further to this, an initiative that drew positive commentary was the embedding of a 'Natural Values Officer' into incident management teams/incident control centres to support the incident controller in developing plans that considered protecting natural values, which happened in the ACT. This role gave natural values a clear voice during the incident management process and additionally provided a point of contact for teams that need to liaise with the Incident Controller. This role has been embedded in fire management practices in some jurisdictions for many years or has been taken on, at least in part, by Planning Officers. However, the roles and functions are not formally recognised in the Australasian Inter-Service Incident Management System (AIIMS) structure, and only occasionally deployed.

Recommendation 7: Effective information resource tools are developed, improved, and made easily available (along with training) to relevant IMT staff.

Recommendation 8: The long-term relationships between conservation managers and emergency agencies should be strengthened. A step towards this is to officially embed Natural Values Officers as key roles in IMTs.

Recommendation 9: The relevant conservation and emergency agencies in each jurisdiction should work together to develop Natural Values Officer training and accreditation.

Finally, the use of the RRATs in the ACT to quickly assess threatened species and determine the work needed to protect them was also thought to be an important undertaking. It should be noted that the NSW equivalent of RRATs, the technical advisory groups, also worked well. Like Natural Values Officers, the roles and functions are not yet formally integrated into the AIIMS structure.

Recommendation 10: Each jurisdiction aims to promptly deploy RRATs as a key element of the bushfire response.

Six of our recommendations (3, 5, 7, 8, 9, and 10) suggest maintaining staff and training in positions that are critical to the biodiversity response during emergency events. The focus here is on bushfires, but some of these roles would be equally as relevant when responding to drought or flood emergencies. A model for such a 'taskforce' of trained staff can be found in the National Biosecurity Response Team (NBRT). The NBRT is a group of governmental staff that have received specialist training so they can be deployed to assist states and territories during a major biosecurity incident. It is made up of personnel from the Australian Government, and State and Territory agencies responsible for agriculture and biosecurity. During emergencies, the team can fill positions in a State Coordination Centre or Local Control Centre, as described in the Biosecurity Incident Management System. They also internally provide training and mentoring to new members. A similar program would be suitable way to incorporate our recommendations into the AIIMS structure and should include staff from both conservation and fire management/emergency agencies.

5.2 Was the emergency response effective?

We asked the respondents whether they thought their conservation programs were effective and therefore, worthwhile. The response was overwhelmingly positive, particularly regarding projects that focussed on the most threatened species. However, in some cases the salvage efforts came too late and insufficient individuals could be caught to make a significant difference to the conservation of those species. In other cases, the fires did not burn the catchments intensely, so the impact on aquatic habitat was likely less than anticipated and captive management may not have been necessary. In those cases, the response was considered appropriate and necessary, but didn't amount to a clear conservation outcome. However, hindsight is always 20–20 and one respondent put it best in saying "Our responses were the most appropriate and really the only course of action at the time and there were no negative outcomes that come to mind. The risk of doing nothing was high and as most of the populations' range was affected by drought and fire, there was a genuine risk of localised extirpations."

6. Conclusion

As noted at the start of this review, the extraordinary 2019/20 bushfire season challenged each jurisdiction's capability and capacity to mount a mass conservation response. The magnitude of the impact of the fires on aquatic communities was made clear by the size and distribution of aquatic mortality events that likely only represent the tip of the iceberg in terms of aquatic life lost. No one had experience responding to an impact of this scale, but most stood up to the challenge. To some degree the results speak for themselves with 24 species and populations either moved to safe habitat or taken into captive management then released to ensure their persistence to aid in their recovery.

The 2019/20 bushfire season was extraordinary, but not entirely unprecedented. Within the last decade, the catastrophic 2003 bushfires in the ACT and NSW, and the 2009 bushfires in Victoria each caused widespread damage to aquatic environments (Carey et al. 2003; Lyon and O'Connor 2008). Our ability to predict bushfires has increased dramatically since then and a clear link has been established between the drying climate and bushfire risk (Van Oldenborgh et al. 2021; Collins et al. 2021). The bushfire season will become longer, and very large fires will become more frequent (Clarke et al. 2020). It will require coordinated Government and non-Government efforts to build resilience. Best practice in emergency response dictates that the response be reviewed regularly, with considered reflection on what occurred in an emergency event and always with a mind to ensuring that we are suitably prepared to respond when the circumstances require.

However, human nature is to forget the previous emergency and focus on the next threat (Trope and Liberman 2010). This focus on the here and now has happened with droughts, floods and fires. Lessons from previous emergency events tend to be filed away and forgotten. This report seeks to summarise the actions taken during the recent experience and draws out key lessons with the view to improving how we all respond to future emergencies. This report and its recommendations are designed to provide aquatic biodiversity managers with the opportunity to reflect on what happened and ensure that we are as prepared as possible for the future.

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Appendix

Appendix A1. Media focussed on the aquatic conservation response to the 2019/20 bushfires

WEB PAGES

2020

January

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[Stocky Galaxias] Double trouble: this plucky little fish survived Black Summer, but there's worse to come. *The Conversation*, 13 July.
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September

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VIDEO

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https://www.facebook.com/LilyDAmbrosioMP/videos/east-gippsland-fish-return/923644038169836/

NEWSPAPER

[Aquatic fauna, Victoria] In a galaxias far, far away is a future saved by science. *The Age*, 19 September, pp. 4–5.

BOOK

John Pickrell Flames of Extinction (2021). University of NSW Press Ltd

SEMINAR

Of Fire & Mud: post fire extraction of threatened aquatic fauna 2020. *SWIFT Seminar*, 26 March.
https://www.swifft.net.au/cb_pages/swifft_seminar_notes_-_biodiversity_after_bushfire.php#post%20fire%20rescue%20aquatic%20fauna

RADIO

ABC Gippsland - Breakfast (06/05/2020 07:10) Dr Tarmo Raadik, Arthur Rylah Institute for Environmental Research, talks about the institute's aquatic intensive care unit to save more than 600 threatened marine species devastated by the East Gippsland bushfires; he talks
http://news.mmu.vic.gov.au/search/?clip=ac3da948013f4fe1b74d6bedd7ffe048

ABC Radio, The World Today (30/12/2020 12:00) Ecologists concerned for wildlife facing multiple threats in the aftermath of the fires
https://www.abc.net.au/radio/adelaide/programs/worldtoday/ecologists-concerned-for-wildlife-year-on-from-fires/13021400

Appendix A2. Questionnaire sent to those who worked on the various aquatic conservation responses during the 2019/20 bushfires

Questionnaire: emergency actions to protect aquatic fauna in response to the 2019/20 bushfires (freshwater fish, crayfish, and mussels)

The purpose of this questionnaire is to capture what each State/Territory did to safe-guard populations of endangered aquatic fauna in response to the 2019/20 mega fires, and to find out what worked and what did not. The collated information will be used to improve our collective response to future threats. Some of this information may be kept in published or unpublished documents or may not be written down yet. Please include any documentation that may address the questions, and feel free to simply refer to these documents in response to questions. All such information will be appropriately acknowledged in the ensuing report. Some of the questions are quite pointed (i.e. questions around fish health in captivity), but be aware that every jurisdiction experienced issues and such information will not be attributed to specific people or organisations. Thank you again for your time, it's greatly appreciated.

Background

1. Prior to the 2019/20 fires, did your State/Territory have a protocol in place for an emergency response to bushfires threatening endangered aquatic species? If so, please provide the relevant document(s). If none, who conceived the process that was followed in 2019/20, and what was the basis of the response?
2. On what date was it decided that there would be a response to the 2019/20 bushfire (month/year is fine)?
3. What governmental department provided funding for the response?
4. Was there any funding put aside for emergency responses that you could draw from? If so, please provide details.

Pre-recovery actions

5. How was the risk to a given species assessed?
6. What risk factors (i.e. threats to species from the fires) initiated a response?
7. At each level, who was required to provide permission to enact the on-ground response (e.g. within your organisation, state government, fire management agency)?

On-ground response actions

7. Please provide an overview of the emergency response measures taken

Collection of threatened animals

8. Please provide detail on the process taken to collect threatened species in the wild and move them either to captivity or away from the threat (e.g. what equipment that was used in the translocation? What data was taken when animals were taken such as WQ and habitat descriptions?)
9. Did any issues arise and how were they overcome?

Captive management

10. Has captive management of aquatic fauna been conducted previously by your agency in response to emergency situations (e.g. drought or fire)? If so, please provide brief details of the captive management programs (What was the emergency? What was the magnitude of these prior efforts i.e. what species/ how many aquarium)?)

11. If an aquarium facility was used in 2019/20, was it pre-existing or developed reactively?

12. How would you describe your aquarium setup? Indoor/outdoor, how many tanks, size of tanks, circulation system, chillers used, filters, stocking density, anything else?

13. How many fish were salvaged and how many were returned to the wild (by species)? Please enter these details into Table 1.

14. Please provide detail of known/suspected causes of deaths in captivity. Were any issues particularly difficult to manage? If so, how were they overcome?

15. Where was each salvaged species taken from, where were they returned to, and when? Please enter these details into Table 1 and include all locations for each species?

Table 1. Details of savage and return efforts for aquatic species

Species	Number taken	Date	Location taken from (site description and coordinates)	Number returned	Date	Location returned to (site description and coordinates)

Post-fire actions

16. What actions were taken to assess biodiversity loss?

17. What actions were taken to assess biodiversity recovery (please provide dates of actions)?

Conclusion

18. How effective do you think any actions undertaken were in protecting the species at risk?

19. What, if anything, hampered your efforts throughout the response (including Pre-recovery, On-ground and Post-fire)

20. What factors could improve aquatic emergency response in the future?

21. Was there any media focussed on your efforts? If so, please provide links.

Further information:

http://www.nespthreatenedspecies.edu.au

This project is supported through funding from the
Australian Government's National Environmental Science Program.

Threatened Species Recovery Hub

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