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Differential impacts of a wildfire and post-fire sedimentation event on platypus and fish populations in a Victorian upland river

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ABSTRACT

Context. Wildfire can affect freshwater ecosystems in many ways, notably when post-fire rainfall washes ash and sediment into waterways. **Aims.** We investigated species-specific effects of bushfire and subsequent channel sedimentation on the abundance of platypus and fish populations in the upper Buffalo River, Australia. **Methods.** Pre- and post-fire population surveys were conducted using fyke nets. **Key results.** There was no evidence that fish numbers declined because of direct fire effects. However, native two-spined blackfish and Macquarie perch numbers dropped dramatically following post-fire sedimentation, whereas non-native redfin perch increased, most likely as a result of migration from a nearby lake. Platypus captures were consistently recorded at all survey sites both before and after the fire and sediment inflows occurred, with many juveniles being recorded in the first post-fire breeding season. **Conclusions.** The platypus's greater resilience to post-fire sediment inflows than that of native fish presumably reflects its reliance on lungs rather than gills and its ability to take refuge in burrows. It also has a broad diet, flexible foraging behaviour, is highly vagile and typically stores enough fat to support fasting for up to 2–3 weeks. **Implications.** Management of fire-affected aquatic ecosystems must consider species-specific responses of freshwater vertebrates to fire.

Keywords: Black Summer, bushfire impacts, channel sedimentation, fire ecology, fish mortality, Macquarie perch, platypus conservation, two-spined blackfish.

Introduction

Impacts of bushfire on freshwater fauna are variable and occur through a variety of mechanisms. Direct fire-related mortality of fish or macroinvertebrates appears to be an uncommon event, being mainly limited to small headwater streams affected by extreme heat or the adsorption of ammonium ions into water from smoke (Gresswell 1999; Minshall 2003; Burton 2005). Indirect post-fire effects on water quality, habitat attributes or resource availability can occur over varying time scales in response to reduced riparian canopy cover (Dwire and Kauffman 2003; Rodríguez-Lozano *et al.* 2015), transport of soluble nutrients and ash, charcoal and eroded soil from adjoining terrestrial habitats (Earl and Blinn 2003; Dahm *et al.* 2015; Sherson *et al.* 2015) or increased catchment runoff, contributing to a greater frequency or magnitude of flood events (Vieira *et al.* 2004). In the case of fish, substantial post-fire mortality has most often been reported following storms that trigger substantial erosion along with high discharge (Minshall 2003). Resulting large loads of suspended ash and sediment have been causally linked to multi-day spikes in dissolved nutrients, altered water conductivity and pH and substantial sags in the concentration of dissolved oxygen (Dahm *et al.* 2015; Sherson *et al.* 2015), and can physically trigger asphyxiation when the gill lamellae of fish become clogged (Bozek and Young 1994). In the best documented Australian study to date, Lyon and O'Connor (2008) reported that a post-fire runoff event in the upper Buckland River resulted in dissolved oxygen falling to as little as 0.2 mg L^{-1} for up to 12 h after a high sediment load entered the reach (as compared to a normal baseline oxygen concentration of 7–10 mg L^{-1}). As a result, fish populations in the affected reach declined by 90–100%,

with newly deposited sediment taking ~2 years to dissipate and fish stocks requiring 3 years to recover. Despite widespread interest in the effect of bushfire on ecological values, published accounts of its impact on aquatic vertebrates other than fish remain rare.

The platypus (*Ornithorhynchus anatinus*) is an apex predator occupying creeks and rivers across the eastern and south-eastern Australian mainland and in Tasmania (Grant 1992). The species consumes a diverse range of mainly benthic invertebrates (Faragher *et al.* 1979; McLachlan-Troup *et al.* 2010; Marchant and Grant 2015; Hawke *et al.* 2022), preferentially foraging in pools at a depth of more than 1 m (Grant 2004), but also utilising edge habitats and shallow riffles (Serena 1994; McLachlan-Troup *et al.* 2010). Although occupying fire-prone habitats across most of its range, the platypus's response to bushfire remains poorly documented. Benthic insect density often drops following substantial movement of ash and sediment to water courses (Gresswell 1999; Minshall 2003) and can decline to near zero after such events (Vieira *et al.* 2004), potentially linking fire-induced environmental change to increased risk of platypus mortality. Alternatively, fire may potentially reduce platypus breeding success. Juvenile numbers are known to vary with the amount of antecedent flow in the 5 months before the platypus breeding season starts in late winter, presumably because the likelihood that a female enters oestrus depends on her accumulated energy reserves, which in turn are affected by the availability of flow-sensitive prey species (Serena *et al.* 2014; Serena and Grant 2017). It is reasonable to infer that platypus reproduction could be influenced by post-fire sedimentation insofar as this reduces platypus food availability, with adverse effects predicted to be most severe when sedimentation events occur in autumn or early winter, i.e. the period when females need to store fat prior to the next breeding season.

In practice, the only published study that has previously investigated the impact of bushfire on a platypus population found that fewer individuals were recorded at fire-affected sites in a river basin in coastal New South Wales (in the first winter following the fire) than at sites located farther downstream or in a control river basin (Bino *et al.* 2021). However, this was confounded by the fact that the entire study area was severely drought-affected in the 3 years prior to the fire, with very low total monthly discharge (≤1 ML) persisting for approximately twice as long in the fire-affected basin as in the control basin. Given that aquatic communities have been found to be affected more profoundly by drought-related hydrological deficits than by bushfire (Verkaik *et al.* 2013), the extent to which antecedent fire, as opposed to drought, contributed to spatial variation in platypus numbers remains unresolved.

The Black Summer bushfire complex burned more than 7×10^6 ha in south-eastern Australia in late 2019 and early 2020 (Silva *et al.* 2020), including nearly three-quarters of the upper Buffalo River catchment in the Ovens River basin. In the case of the Buffalo River, this was followed by substantial rain falling in early autumn, with its associated risk of aquatic impacts occurring by erosion and sedimentation. This sequence of events provided an opportunity to evaluate how fish populations changed over time in the fire- and sediment-affected reaches and compare these results with those previously documented by Lyon and O'Connor (2008) in the nearby Buckland River. In addition, we opportunistically tested the following two hypotheses concerning fire-related effects on the platypus population of Buffalo River: (1) as an air-breathing species, the platypus will be less vulnerable than are fish to degraded water quality caused by post-fire sediment inflows; and (2) few or no juveniles will be produced in the first post-fire breeding season because of presumed impacts on maternal foraging success.

Materials and methods

The study area comprised ~21 km of the Buffalo River extending upstream of Lake Buffalo (a large water storage completed in 1965, with a surface area of 341 ha and a capacity of ~24 000 ML) in north-eastern Victoria (Fig. 1). The river channel is a fifth- to sixth-order water course (calculated using the Strahler method; Ranalli and Scheidegger 1968) that typically measures 6–20 m wide and 0.3–2 m deep. On the basis of daily flow records obtained since mid-1965 (see below), median surface discharge in the study area is 157 ML day^{-1}, with nil flow having been recorded on only 12 days since mid-1965 (most recently in February 2007). By comparison, median discharge in the years immediately before or within the study period was 165.6 ML day^{-1} (in 2017), 99.9 ML day^{-1} (2018), 81.2 ML day^{-1} (2019), 333.9 ML day^{-1} (2020) and 103.1 ML day^{-1} (1 January–8 March 2021); minimum daily flow in the driest 2 years (2018 and 2019) was respectively 12.3 and 2.2 ML. Approximately 90% of the associated water catchment area is covered by native hardwood forest dominated by *Eucalyptus* species. Given the densely forested nature of the catchment, unplanned wildfires often occur in dry summer periods and have affected parts of the Buffalo River system on three occasions since 2000. Most recently, the entire riverine study area and ~70% of the associated catchment were burnt during the Black Summer bushfires. Intense fire passed through the study area in December 2019, resulting in widespread defoliation and charring of trees and loss of lower-growing shrubby vegetation and leaf litter through the entire study area; this fire was not considered to be fully extinguished across the associated catchment until February 2020.

Fish and platypus populations were surveyed using fyke nets, set with the cod end securely fastened above the water surface to protect air-breathing fauna from drowning. Nets targeting fish featured a single netting wing stretched in front of the entrance; those targeting platypus were set

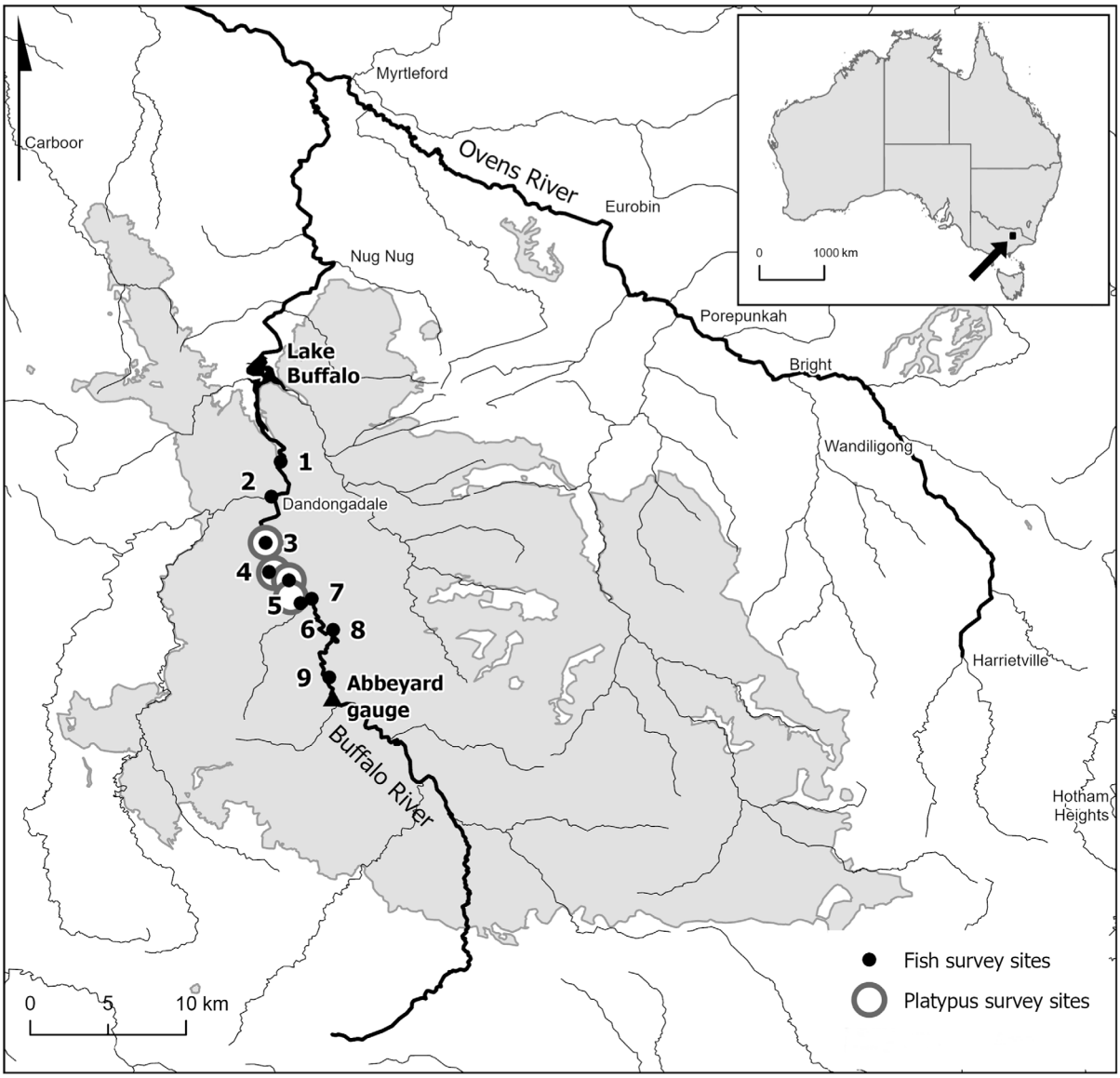

Fig. 1. The upper Buffalo River catchment, showing the extent of area burnt in the Black Summer bushfires (in grey). Numbered black dots denote survey sites that targeted fish (with platypus recorded as by-catch) in 2018 and 2020; larger unnumbered open dots denote survey sites that targeted platypus (with fish recorded as by-catch) in 2021. Arrow on inset national map indicates the study area location.

in pairs and featured two netting wings stretched laterally, so the entire channel (apart from net entrances) was blocked (Serena and Williams 2012; also see Supplementary Fig. S1). Both methods have been designed to optimise captures of their respective target taxa; nets set for platypus are expected to be less effective at capturing fish, whereas those set to capture fish are expected to be less effective at capturing platypus.

Nets targeting fish were set on three occasions, respectively comprising a pre-fire sampling period (in March 2018, 22 months before the study area was burnt), post-fire and pre-flood sampling period (in late January 2020, 5 weeks after the study area was burnt) and post-flood sampling period (in December 2020, 35 weeks after the first substantial post-fire storm occurred). Nets were set at Sites 2 and 8 in Fig. 1 in March 2018 (netting effort = 8 net-nights, 1 net-night = 1 single-wing fyke net set overnight), at Site 8 in January 2020 (36 net-nights), and at Sites 1–9 inclusive in December 2020 (39 net-nights). At each site, nets were typically deployed across ~200 m of channel (but 600 m in the case of Site 8) from late afternoon until early the following morning. Total fish length (tip of snout to tail tip or apex of tail fork, depending on tail shape) was recorded to the nearest millimetre. The number of platypus captures occurring at each site (but not sex, age or physical condition) was also recorded. To provide an index of relative abundance, catch-per-unit-effort (CPUE)

was calculated as the number of individuals of a given fish species captured per net-night.

Two nets targeting platypus (one facing upstream and one facing downstream) were set at each of four sites located at or near fish survey sites 3–6 on the night of 9 March 2021, thereby coinciding with the peak annual period for juvenile platypus captures in Victoria (Serena and Williams 2012). Platypus CPUE in fyke nets is normally calculated as the number of captures recorded per site per night (Serena and Williams 2012) and assumes that nets are set on only one night in a given netting session to reduce the likelihood that net-avoidance may bias results (Griffiths *et al.* 2013). To provide a reasonably consistent metric for reporting the frequency of platypus captures in fyke nets targeting fish and those targeting platypus, this was summarised as the mean number of platypus captures recorded per site in a given netting session. Captured animals were assigned to one of five sex–age classes (juvenile or first-year males; juvenile or first-year females; subadult or second-year males; subadult or adult females ≥12 months old; adult males ≥24 months old) on the basis of the size and shape of calcaneal spurs or spur sheaths (Williams *et al.* 2013). Physical condition was assessed using an ordinal five-point scale to gauge the amount of fat stored in the tail (tail volume index, Grant and Carrick 1978). Fish encountered as by-catch in platypus nets were identified to species and their length (defined as above) was recorded to the nearest millimetre.

Daily surface discharge (ML day^{-1}) was recorded on 99.9% of days from 1 July 1965 to 14 May 2021 at an automated gauging station located ~1.2 km upstream of the study area (Victorian Department of Environment, Land, Water and Planning Monitoring site 40322, Buffalo River at Abbeyard), with monthly measurements of total suspended solids (TSS, mg L^{-1}) recorded at the same location by DELWP contractors from April 2020 to April 2021. Mean daily discharge and monthly TSS data were downloaded from the DELWP water-monitoring portal (data.water.vic.gov.au) on 15 May 2021.

Summary statistics (mean ± standard error, s.e.m.) and two-sample Student's *t*-tests (used to compare fish lengths) were calculated using SYSTAT (ver. 8.0, SPSS), with significance set at 0.05.

Field activities (APC) were authorised by Victorian Wildlife Research Permit 10009537, Fisheries Research Permit RP553 and APC Animal Ethics Committee Approval 19.1. Field activities (by Arthur Rylah Institute) were authorised by Victorian Fisheries Research Permit RP827, FFG Research Permit 10008367 and Arthur Rylah Institute Animal Ethics Committee Approval 19/004.

Results

The first substantial post-fire storm in the study area occurred in early March 2020, when 75 mm of rain was recorded in a single 24-h period just downstream of the study area at Lake Buffalo (Bureau of Meteorology Weather-monitoring station 083079). Surface discharge at the Abbeyard gauge increased from a mean 38.3 ± 5.1 ML day^{-1} (range = 8.7–219.3) in January and February 2020 to respectively 1422 and 1303 ML day^{-1} on 5 and 6 March (equating to the 93rd and 92nd percentiles for daily discharge since mid-1965; Fig. 2). The storm also promoted widespread mass movement of ash and eroded soil into the Buffalo River from neighbouring steep slopes throughout the study area and farther upstream (Fig. 3), with a particularly large landslip observed near the Catherine River confluence, ~10 km upstream of the Abbeyard gauge (Glen Johnson, DELWP, pers. comm.). By April, when monthly water-quality monitoring was initiated at Abbeyard, the amount of total suspended solids had declined to 2 mg L^{-1} (Fig. 4). TSS increased modestly in May (to 88 mg L^{-1}) after surface discharge rose to 4435 ML day^{-1} on 30 April, but declined again by June, with TSS remaining low through the rest of the study period (with a maximum recorded value of 12 mg L^{-1} in July). Some fine inorganic benthic sediment presumed to have originated as post-fire depositional material was still evident when nets were set in December 2020, but had almost entirely disappeared by March 2021, when cobbles again dominated the channel substrate.

Two fish species were recorded in pre-fire sampling (March 2018), including native two-spined blackfish (*Gadopsis bispinosus*; CPUE = 0.50) and Macquarie perch (*Macquaria australasica*; CPUE = 0.62). In post-fire and pre-flood sampling (January 2020), blackfish (CPUE = 1.0) and Macquarie perch (CPUE = 0.69) were again the most commonly recorded species, although non-native brown trout (*Salmo trutta*) (CPUE = 0.11) was also recorded. In short, there was no

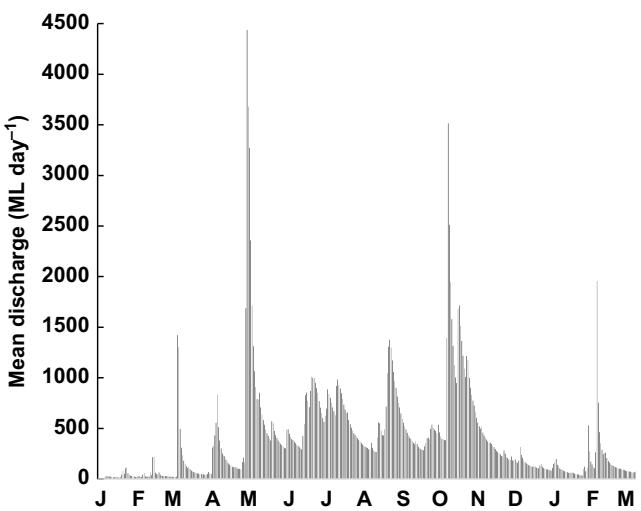

Fig. 2. Surface discharge (ML day^{-1}) recorded in the upper Buffalo River at Monitoring site 403222 (Abbeyard) from 1 January 2020 to 9 March 2021.

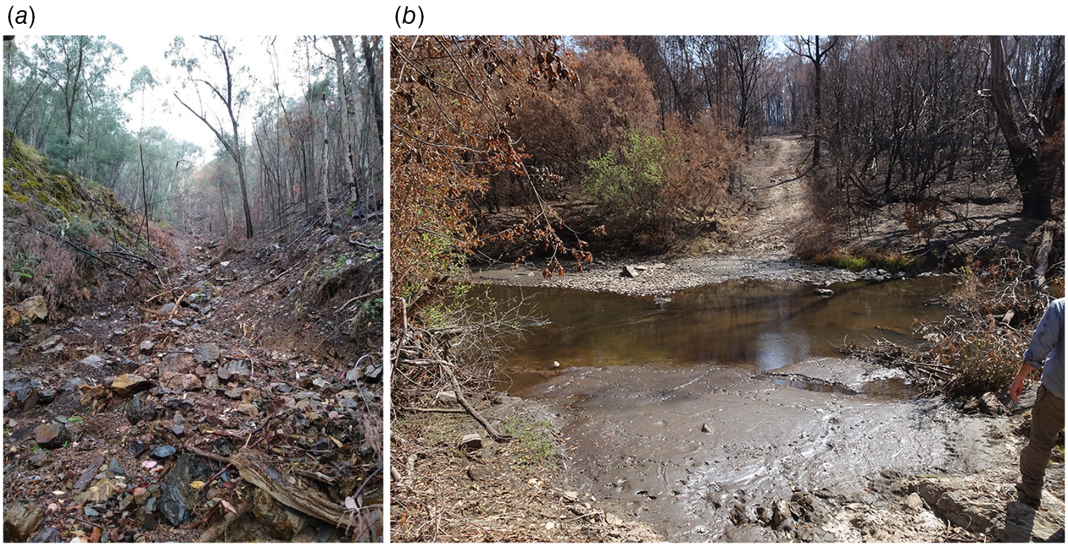

Fig. 3. Examples of (*a*) a gully line in the upper Buffalo River catchment affected by mass movement of ash and soil following substantial post-fire rainfall in March 2020 and (*b*) subsequent deposition of channel sediment in the Buffalo River at Durling Track, between fish survey sites 5 and 6 in Fig. 1. Both photos were taken in April 2020.

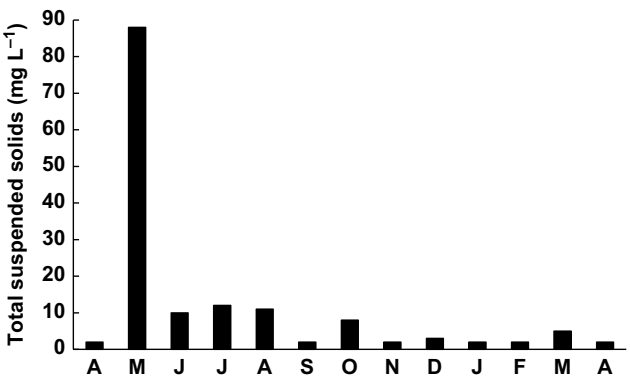

Fig. 4. Total suspended solids (mg L^{-1}) recorded in the upper Buffalo River at Monitoring site 403222 (Abbeyard) at monthly intervals from April 2020 to April 2021.

evidence that any fish species declined in the study area as a direct outcome of fire. However, post-flood sampling (December 2020) indicated that numbers of blackfish (CPUE = 0.13) and Macquarie perch (CPUE = 0.08) had respectively declined by 87 and 88% since January 2020, with relatively fewer brown trout individuals also being captured in December (CPUE = 0.05). Conversely, non-native redfin perch (*Perca fluviatilis*) appeared for the first time in post-flood sampling (CPUE = 0.41), accounting for 59% of all the fish recorded in December 2020. Although redfin perch was recorded as far upstream as Site 8, 75% of captures occurred within ~10 km of Lake Buffalo at Sites 1–4, with all post-flood captures of Macquarie perch being recorded in the same area. By contrast, 80% of post-flood captures of blackfish occurred at Sites 7–9, in the upper 5 km of the study area.

Along with blackfish numbers being much lower in December than in January, their mean length increased significantly from 173 mm ± 3.5 (range = 128–221 mm, $n = 35$) in post-fire and pre-flood sampling to 230 mm ± 9.8 (range = 204–261 mm, $n = 5$) in post-flood sampling ($t = 5.749$, d.f. = 38, $P < 0.001$). Similarly, the mean length of Macquarie perch increased from 158 mm ± 13.6 (range = 107–361 mm, $n = 24$) in post-fire and pre-flood sampling to 231 mm ± 49.8 (range = 174–330 mm, $n = 3$) in post-flood sampling (Fig. 5). The three Macquarie perch individuals captured in December were larger than all but four (83%) of the individuals captured in January. However, reflecting the low December sample size and a high s.e.m., lengths of Macquarie perch did not differ significantly between the two sampling periods ($t = 1.727$, d.f. = 25, $P = 0.097$). The mean length of redfin perch captured in post-flood sampling was 134 mm ± 3.2 (range = 117–156 mm, $n = 16$).

Platypuses were consistently captured at every site where nets targeting fish were set from 2018 to 2020. The frequency of platypus captures in fyke nets in Victoria is characteristically augmented by the occurrence of juveniles in March, with many fewer juveniles being encountered in late January and none as early as December (Serena and Williams 2012). The mean number of captures recorded per site as by-catch was 2.5 ± 1.5 in pre-fire sampling in March 2018 (range = 1–4, $n = 2$ sites), two in post-fire and pre-flood sampling in late January 2020 ($n = 1$ site) and 1.7 ± 0.3 in post-flood sampling in December 2020 (range = 1–4, $n = 9$ sites). The mean number of platypus captures recorded per site in nets targeting this species in March 2021 was 3.0 ± 0.6 (range = 2–4, $n = 4$ sites). This included two

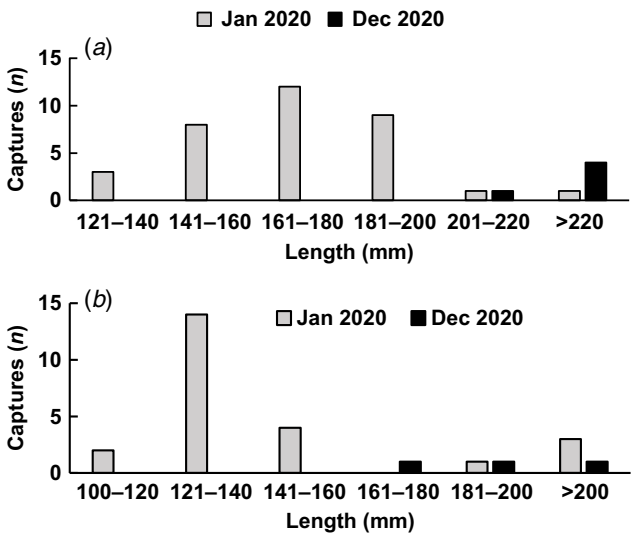

Fig. 5. Total length of (*a*) two-spined blackfish and (*b*) Macquarie perch captured in the Buffalo River study area in January 2020 (5 weeks after bushfire) and December 2020 (35 weeks after post-fire flooding).

adult males, four adult or subadult females, three juvenile males and three juvenile females, all of which were in above-average condition (tail volume index = 2 (n = 3) or 2/nearly 1 (n = 9)). Only one fish (a redfin perch, 110 mm in length) was recorded as by-catch.

Discussion

Our study has provided insight into the relative importance of direct and longer-term impacts of bushfire on native fish and platypus populations sharing an upland river environment. In the case of fish, previous research has concluded that direct fire-related mortality is typically limited to headwater streams of Strahler Stream order 3 or less (Gresswell 1999). In line with this generalisation, our study area (Stream order 5–6, with median daily flow of 157 ML) continued to support substantial numbers of Macquarie perch and two-spined blackfish in surveys conducted after bushfire but before subsequent high flows occurred, with fish abundance being inferred to be as high or higher than 22 months prior to the fire.

In the absence of other plausible mechanisms, we infer that the loss of close to 90% of two-spined blackfish and Macquarie perch from the Buffalo River study area following post-fire flooding was likely to have been caused by asphyxiation and possibly subsequent habitat change or reduced food resources linked to the sediment deposition that occurred in March. Similarly, 90–100% of both native and non-native fish species died in badly affected reaches of the nearby Buckland River catchment following the post-fire sedimentation event studied by Lyon and O'Connor (2008). It remains unknown whether the small number of relatively large-bodied blackfish and Macquarie perch encountered in December managed to survive the sediment slug or whether they subsequently migrated into the study area. Blackfish have previously been found to be early and effective colonisers of badly affected post-fire sedimentation sites in the nearby Buckland River (Lyon and O'Connor 2008). Similarly, some or all of the Macquarie perch recorded ~35 weeks after large amounts of sediment were deposited in our study area may well have been migrants from Lake Buffalo, where this species has previously been recorded in low numbers during *ad hoc* fish population surveys, including a post-fire survey conducted in February 2020 (Arthur Rylah Institute, unpubl. data). The lake plausibly provided a refuge from both fire and post-fire sedimentation impacts given its large surface area and depth. Furthermore, Macquarie perch is a relatively mobile species that will travel many kilometres to a spawning ground (Tonkin *et al.* 2018) or to disperse (Lutz *et al.* 2021). Consistent with this hypothesis, all of the individuals captured in the river in post-flood sampling were encountered at the downstream end of the study area, within ~10 km of the lake.

Non-native redfin perch was not encountered in fyke-netting surveys conducted either before or a few weeks after the upper Buffalo River catchment was burnt, but comprised more than half of all fish recorded 1 year later, when numbers of native fish had dropped dramatically. Redfin is appropriately described as a highly vagile species (Lintermans 2007) and was again captured mainly at the lower end of our study area near Lake Buffalo, which is known to support a large redfin population on the basis of *ad hoc* fish surveys conducted between 2004 and 2020 (Arthur Rylah Institute, unpubl. data). Although the mechanisms contributing to redfin perch appearing in the study area remain unclear, post-fire habitat disruption has been posited to encourage invasion by non-native fish species, especially if accompanied by reduced native fish density (Dunham *et al.* 2003).

Our results support the hypothesis that platypus populations are less sensitive than are native fish populations to adverse effects of post-fire sediment slugs, with no evidence that platypus numbers declined notably along the upper Buffalo River between January and December 2020, albeit based on limited sampling. The platypus's ability to survive this form of disturbance presumably reflects the fact that it is an amphibious species that relies on lungs rather than gills to breathe. Its survival is therefore not directly jeopardised by low concentrations of dissolved oxygen, and it can leave the water and take refuge in a burrow to avoid massively increased loads of suspended solids. This species is also expected to survive the immediate direct impacts of bushfire as platypus burrows are typically located at the water's edge in well-consolidated earthen banks rising 1 m or more above the water surface (Serena *et al.* 1998).

Accordingly, although the thickness of a burrow roof can occasionally be as little as 12 cm (Serena 1994), a platypus is normally expected to be well insulated from exposure to flames, radiant heat and smoke.

We hypothesised that platypus reproduction in the upper Buffalo River would be substantially reduced by presumed impacts on foraging success arising from the sedimentation event occurring in March, i.e. near the start of the 5-month period deemed to be critical for females to amass sufficient energy reserves prior to entering oestrus (Serena *et al.* 2014; Serena and Grant 2017). Contrary to this hypothesis, 1.5 juveniles were recorded per non-juvenile female in the first post-fire breeding season in the Buffalo River, which corresponds to the upper limit recorded in the very productive platypus population occupying a similar-sized waterbody, the upper Shoalhaven River, in more than two decades of reproductive studies (Serena and Grant 2017). Although no pre-fire platypus reproductive data are available to ascertain whether fewer juveniles were produced in the Buffalo River study area than would have occurred in the absence of wildfire, the high ratio of juveniles to females is consistent with the platypus being reproductively resilient to fire. In practice, sufficient juveniles were produced in the 2020–21 breeding season to support a potential doubling of the resident population in the sampled area, implying that natural recruitment should compensate fairly rapidly for any adult losses that may have been directly or indirectly triggered by fire.

Our platypus findings are mainly derived from opportunistic monitoring based on limited spatial and temporal sampling. Additional field studies are needed both to confirm our findings more widely and to ascertain how the platypus responds, physically and behaviourally, to the marked reduction in invertebrate prey expected to occur after a major post-fire sedimentation event. Given practical constraints on implementing such studies, relevant data are unlikely to be available in the near future. However, it is well established that adult platypus home ranges often encompass 2 km or more of channel, with adults occasionally known to travel more than an order of magnitude farther (Serena and Williams 2013). It is therefore plausible that individuals may respond to severe post-fire sedimentation by temporarily shifting their foraging activity to unaffected habitats (e.g. side channels), either within an established home range or elsewhere in the catchment.

Presuming that alternative refuge habitats are not available, Hulbert and Grant (1983) have estimated that an adult platypus has enough body fat so that it can fast, on average, for up to 3 weeks in summer or 2 weeks in winter. In addition, a platypus's diet may potentially include the carcasses of fish or other organisms killed by a sediment slug, helping to compensate for the predicted immediate drop in benthic insect biomass. Although the platypus lacks true teeth and masticates its prey using keratinous grinding pads located at the back of the jaw (Griffiths 1978), goldfish (*Carassius auratus*) is routinely killed and ingested in captivity (Krueger *et al.* 1992) and frog remains have been recovered from a platypus cheek pouch in the wild (Faragher *et al.* 1979). Furthermore, some invertebrate taxa that are predicted to be palatable to a platypus (such as oligochaete worms) may remain unaffected by post-fire siltation that causes sizeable reductions in insect populations (Whitney *et al.* 2015).

All of the platypus encountered in the Buffalo River study area were assessed to be in above-average physical condition when captured ~12 months after substantial post-fire sedimentation had occurred. Benthic insect density may largely or entirely recover from such an event in less than 1 year (Earl and Blinn 2003; Vieira *et al.* 2004; Verkaik *et al.* 2015; Webster *et al.* 2022), with the recovery being typically led by disturbance-adapted taxa in the families Simuliidae, Chironomidae and Baetidae (Vieira *et al.* 2004; Malison and Baxter 2010; Verkaik *et al.* 2013, 2015; Rugenski and Minshall 2014), all of which are eaten by the platypus (Faragher *et al.* 1979; Marchant and Grant 2015). A shift to r-selected taxa with high production to biomass ratios has been found to contribute to increased post-fire abundance of benthic insects in North American, European and Australian waterbodies (Vieira *et al.* 2004; Malison and Baxter 2010; Verkaik *et al.* 2015), with abundance in Victorian streams increasing by 75% less than 1 year after they were affected by bushfire (Verkaik *et al.* 2015). Alternatively, above-average platypus condition in the Buffalo River study area in March may have been at least partly mediated by reduced food competition with fish, given that increased redfin perch numbers only partly compensated for the reduced numbers of two-spined blackfish and Macquarie perch recorded in December.

Supplementary material

Supplementary material is available online.

References

Bino G, Hawke T, Kingsford RT (2021) Synergistic effects of a severe drought and fire on platypuses. *Science of the Total Environment* **777** (2021) 146137. doi:10.1016/j.scitotenv.2021.146137

Bozek MA, Young MK (1994) Fish mortality resulting from delayed effects of fire in the Greater Yellowstone Ecosystem. *Great Basin Naturalist* **54**, 91–95.

Burton TA (2005) Fish and stream habitat risks from uncharacteristic wildfire: observations from 17 years of fire-related disturbances on the Boise National Forest, Idaho. *Forest Ecology and Management* **211**, 140–149. doi:10.1016/j.foreco.2005.02.063

Dahm CN, Candelaria-Ley RI, Reale CS, Reale JK, Van Horn DJ (2015) Extreme water quality degradation following a catastrophic forest fire. *Freshwater Biology* **60**, 2584–2599. doi:10.1111/fwb.12548

Dunham JB, Young MK, Gresswell RE, Rieman BE (2003) Effects of fire on fish populations: landscape perspectives on persistence of native fishes and nonnative fish invasions. *Forest Ecology and Management* **178**, 183–196. doi:10.1016/S0378-1127(03)00061-6

Dwire KA, Kauffman JB (2003) Fire and riparian ecosystems in landscapes of the western USA. *Forest Ecology and Management* **178**, 61–74. doi:10.1016/S0378-1127(03)00053-7

Earl SR, Blinn DW (2003) Effects of wildfire ash on water chemistry and biota in South-Western USA streams. *Freshwater Biology* **48**, 1015–1030. doi:10.1046/j.1365-2427.2003.01066.x

Faragher RA, Grant TR, Carrick FN (1979) Food of the platypus (*Ornithorhynchus anatinus*) with notes on the food of brown trout (*Salmo trutta*) in the Shoalhaven River, NSW. *Australian Journal of Ecology* **4**, 171–179. doi:10.1111/j.1442-9993.1979.tb01207.x

Grant TR (1992) The historical and current distribution of the platypus, Ornithorhynchus anatinus, in Australia. In 'Platypus and Echidnas'. (Ed. ML Augee) pp. 232–254. (Royal Zoological Society of New South Wales: Sydney, NSW, Australia)

Grant TR (2004) Depth and substrate selection by platypuses, *Ornithorhynchus anatinus*, in the lower Hastings River, New South Wales. *Proceedings of the Linnean Society of New South Wales* **125**, 235–241.

Grant TR, Carrick FN (1978) Some aspects of the ecology of the platypus, *Ornithorhynchus anatinus*, in the upper Shoalhaven River, New South Wales. *Australian Zoologist* **20**, 181–199.

Gresswell RE (1999) Fire and aquatic ecosystems in forested biomes of North America. *Transactions of the American Fisheries Society* **128**, 193–221. doi:10.1577/1548-8659(1999)128<0193:FAAEIF>2.0.CO;2

Griffiths M (1978) 'The Biology of the Monotremes.' (Academic Press: New York, NY, USA)

Griffiths J, Kelly T, Weeks A (2013) Net-avoidance behaviour in platypuses. *Australian Mammalogy* **35**, 245–247. doi:10.1071/AM12051

Hawke T, Bino G, Shackleton ME, Ross AK, Kingsford RT (2022) Using DNA metabarcoding as a novel approach for analysis of platypus diet. *Scientific Reports* **12**, 2247. doi:10.1038/s41598-022-06023-y

Hulbert AJ, Grant TR (1983) A seasonal study of body condition and water turnover in a free-living population of platypuses, *Ornithorhynchus anatinus* (Monotremata). *Australian Journal of Zoology* **31**, 109–116. doi:10.1071/ZO9830109

Krueger B, Hunter S, Serena M (1992) Husbandry, diet and behaviour of platypus *Ornithorhynchus anatinus* at Healesville Sanctuary. *International Zoo Yearbook* **31**, 64–71. doi:10.1111/j.1748-1090.1991.tb02364.x

Lintermans M (2007) 'Fishes of the Murray–Darling Basin: an introductory guide.' (Murray–Darling Basin Commission: Canberra, ACT, Australia)

Lutz ML, Tonkin Z, Yen JDL, Johnson G, Ingram BA, Sharley J, Lyon J, Chapple DG, Sunnucks P, Pavlova A (2021) Using multiple sources during reintroduction of a locally extinct population benefits survival and reproduction of an endangered freshwater fish. *Evolutionary Applications* **14**, 950–964. doi:10.1111/eva.13173

Lyon PJ, O'Connor JP (2008) Smoke on the water: can riverine fish populations recover following a catastrophic fire-related sediment slug? *Austral Ecology* **33**, 794–806. doi:10.1111/j.1442-9993.2008.01851.x

Malison RL, Baxter CV (2010) Effects of wildfire of varying severity on benthic stream insect assemblages and emergence. *Freshwater Science* **29**, 1324–1338. doi:10.1899/09-022.1

Marchant R, Grant TR (2015) The productivity of the macroinvertebrate prey of the platypus in the upper Shoalhaven River, New South Wales. *Marine and Freshwater Research* **66**, 1128–1137. doi:10.1071/MF14301

McLachlan-Troup TA, Dickman CR, Grant TR (2010) Diet and dietary selectivity of the platypus in relation to season, sex and macroinvertebrate assemblages. *Journal of Zoology* **280**, 237–246. doi:10.1111/j.1469-7998.2009.00645.x

Minshall GW (2003) Responses of stream benthic macroinvertebrates to fire. *Forest Ecology and Management* **178**, 155–161. doi:10.1016/S0378-1127(03)00059-8

Ranalli G, Scheidegger AE (1968) Topological significance of stream labelling methods. *Hydrological Sciences Journal* **13**, 77–85. doi:10.1080/02626666809493628

Rodríguez-Lozano P, Rieradevall M, Rau MA, Prat N (2015) Long-term consequences of a wildfire for leaf-litter breakdown in a Mediterranean stream. *Freshwater Science* **34**, 1482–1493. doi:10.1086/683432

Rugenski AT, Minshall GW (2014) Climate-moderated responses to wildfire by macroinvertebrates and basal food resources in montane wilderness streams. *Ecosphere* **5**, 1–24. doi:10.1890/ES13-00236.1

Serena M (1994) Use of time and space by platypus (*Ornithorhynchus anatinus*: Monotremata) along a Victorian stream. *Journal of Zoology* **232**, 117–131. doi:10.1111/j.1469-7998.1994.tb01563.x

Serena M, Grant TR (2017) Effect of flow on platypus (*Ornithorhynchus anatinus*) reproduction and related population processes in the upper Shoalhaven River. *Australian Journal of Zoology* **65**, 130–139. doi:10.1071/ZO17025

Serena M, Williams GA (2012) Effect of sex and age on temporal variation in the frequency and direction of platypus (*Ornithorhynchus anatinus*) captures in fyke nets. *Australian Mammalogy* **34**, 75–82. doi:10.1071/AM10056

Serena M, Williams GA (2013) Movements and cumulative range size of the platypus (*Ornithorhynchus anatinus*) inferred from mark–recapture studies. *Australian Journal of Zoology* **60**, 352–359. doi:10.1071/ZO12121

Serena M, Thomas JL, Williams GA, Officer RCE (1998) Use of stream and river habitats by the platypus, *Ornithorhynchus anatinus*, in an urban fringe environment. *Australian Journal of Zoology* **46**, 267–282. doi:10.1071/ZO98034

Serena M, Williams GA, Weeks AR, Griffiths J (2014) Variation in platypus (*Ornithorhynchus anatinus*) life-history attributes and population trajectories in urban streams. *Australian Journal of Zoology* **62**, 223–234. doi:10.1071/ZO13079

Sherson LR, Van Horn DJ, Gomez-Velez JD, Crossey LJ, Dahm CN (2015) Nutrient dynamics in an alpine headwater stream: use of continuous water quality sensors to examine responses to wildfire and precipitation events. *Hydrological Processes* **29**, 3193–3207. doi:10.1002/hyp.10426

Silva LGM, Doyle KE, Duffy D, Humphries P, Horta A, Baumgartner LJ (2020) Mortality events resulting from Australia's catastrophic fires threaten aquatic biota. *Global Change Biology* **26**, 5345–5350. doi:10.1111/gcb.15282

Tonkin Z, Lyon JP, Moloney P, Balcombe SR, Hackett G (2018) Spawning-stock characteristics and migration of a lake-bound population of the endangered Macquarie perch *Macquaria australasica*. *Journal of Fish Biology* **93**, 630–640. doi:10.1111/jfb.13731

Verkaik I, Vila-Escalé M, Rieradevall M, Prat N (2013) Seasonal drought plays a stronger role than wildfire in shaping macroinvertebrate communities of Mediterranean streams. *International Review of Hydrobiology* **98**, 271–283. doi:10.1002/iroh.201201618

Verkaik I, Vila-Escalé M, Rieradevall M, Baxter CV, Lake PS, Minshall GW, Reich P, Prat N (2015) Stream macroinvertebrate community responses to fire: are they the same in different fire-prone biogeographic regions? *Freshwater Science* **34**, 1527–1541. doi:10.1086/683370

Vieira MKM, Clements WH, Guevara LS, Jacobs BF (2004) Resistance and resilience of stream insect communities to repeated hydrologic disturbances after a wildfire. *Freshwater Biology* **49**, 1243–1259. doi:10.1111/j.1365-2427.2004.01261.x

Webster JS, Gido KB, Hedden SC, Propst DL, Whitney JE (2022) Response of arid-land macroinvertebrate communities to extremes of drought, wildfire, and monsoonal flooding. *River Research and Applications* **38**, 832–845. doi:10.1002/rra.3949

Whitney JE, Gido KB, Pilger TJ, Propst DL, Turner TF (2015) Consecutive wildfires affect stream biota in cold- and warmwater dryland river networks. *Freshwater Science* **34**, 1510–1526. doi:10.1086/683391

Williams GA, Serena M, Grant TR (2013) Age-related change in spurs and spur sheaths of the platypus (*Ornithorhynchus anatinus*). *Australian Mammalogy* **35**, 107–114. doi:10.1071/AM12011

Data availability. The data that support this study will be shared upon reasonable request to Jarod Lyon (fish-related data) or the corresponding author (platypus-related data).

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