

# **Fire and water in the Blue Mountains- lessons from a long term monitoring program**

Alice Blackwood<sup>1</sup>, Amy St Lawrence<sup>1</sup>, Ian Wright<sup>2</sup>, Geoffrey Smith<sup>1</sup>, Gillian Fitzgerald<sup>1</sup>

1. Blue Mountains City Council, Locked Bag 1005, Katoomba, NSW 2780 Email: [ablackwood@bmcc.nsw.gov.au](mailto:ablackwood@bmcc.nsw.gov.au)

2. School of Science, Western Sydney University, Penrith, 2750

## **Key Points**

- The bushfires of 2019-20 burnt 71% of the Greater Blue Mountains World Heritage Area
- Data from several long term monitoring sites was analysed to investigate the impact of fire on waterway health.
- Results showed that the stream invertebrate communities displayed a much higher degree of resilience to bushfire than was expected
- This work demonstrates the value of long term monitoring programs, and emphasises the need to build and maintain resilience wherever possible.

## **Abstract**

The Australian bushfires of summer 2019-20 had drastic impacts on catchments and waterways that are yet to be fully understood. Seventy-one percent of the Greater Blue Mountains World Heritage Area (GBMA) was affected by these fires. To date, much of the research on the impact of fires has focused on catchment hydrology and physical water quality. Less is understood about impacts on aquatic macroinvertebrates, and hence the ecological health of waterways post-fire.

This paper analyses long-term data from Blue Mountains City Council's aquatic monitoring program, to assess the impact of the bushfires on headwater streams in the GBMA. We compare the macroinvertebrate community, waterway health ratings, and basic physical water quality parameters pre-fire and post fire, at sites with over twenty years' of data.

The results from this research showed that the stream invertebrate communities displayed a much higher degree of resilience to bushfire than was expected. Some measures of stream ecological health were actually higher at more recently burnt sites. The need for management that builds the resilience of waterways with urban catchments is emphasised by these results, as well as the value of long term monitoring programs. This contributes to a growing body of research on fire impacts, building capacity for adaptive management in the Blue Mountains area and beyond.

## **Keywords**

Waterway health, bushfire, monitoring, macroinvertebrates, ecology, adaptive management

## **Introduction**

The Australian bushfires of summer 2019-20 had drastic impacts on catchments and waterways that are yet to be fully understood. One area that was particularly impacted was the Greater Blue Mountains World Heritage Area (GBMA). Over seventy percent of this area was affected by fires that burnt from the end of October 2019 to early February 2020. Torrential rain then followed in February, which had a significant impact, causing flash flooding, erosion of waterways and transportation of large volumes of sediment, debris and ash throughout the catchments. Given these extreme events, it is expected that we would see impacts on waterway health, but the extent and nature of these impacts is not yet known.

In December 2020, the International Union for the Conservation of Nature (IUCN) released a new Conservation Outlook Assessment for the GBMA. This gives an overview of the current status of key values and threats in the area. Largely due to the devastating impact of the fires, the IUCN downgraded the status of the area to Significant Concern. They state that “better planning and adaptive management will be important to address threats, especially climate change and its unfolding effects including drought and uncontrollable fire.” An important part of adaptive management is reliable scientific data, which enables informed management decisions.

Fortunately, long term ecological monitoring data of Blue Mountains streams does exist. This is thanks to Blue Mountains City Council’s (henceforth ‘Council’) Waterway Health Monitoring Program, which monitors stream health at over 70 locations throughout the Blue Mountains Local Government Area, and has been running since 1998. After the 2019-20 fires, an opportunity was seen to conduct additional post fire monitoring at affected sites. This enabled Council to monitor for acute impacts and be able to respond with rapid management actions if necessary. It also provided an opportunity to contribute to broader knowledge of the impact of fire on waterways.

In this paper, we conduct a preliminary analysis of the long term waterway health data, using both macroinvertebrate and water quality data, to assess the impact of fire history on stream health at monitoring sites burnt in the 2019-20 fires. We discuss directions for future analysis and management implications for the Blue Mountains and beyond.

## **Field Sites and Methods**

### *Field sites and samples*

Of more than 70 sites currently included in Council’s Waterway Health Monitoring Program, 9 were burnt in the 2019-20 bushfires. Of these, 7 were chosen for focused analysis and additional post-fire monitoring throughout 2020. Table 1 summarises the key details of these sites, including fire history, and Figure 1 shows site locations in relation to nearby towns. Fire history was determined by using publicly available fire history maps (DPIE, 2010). Interestingly, more than half of these sites have been burnt three or more times since 1993. Generally these sites are sampled once per year, in autumn.

**Table 1. Summary details of waterway health monitoring sites burnt in the 2019-20 bushfires (05GMVR was only sampled until 2011, after which it was replaced with the new location at 05.2GMVR)**

Site	Waterway	Closest town	Samples since 1998	Fire History (x indicates site burnt in that fire)			
				1993-4	2006-7	2013-14	2019-20
02GBLR	Jungaburra Brook	Bell	31	x	x	x	x
03BMV	Fairy Dell Creek	Mt Victoria	19		x	x	x
04GMV	Grose River tributary	Mt Victoria	24	x	x	x	x
05.2GMVR	Asgard Brook	Mt Victoria	19	x	x	x	x
05GMVR	Asgard Brook	Mt Victoria	9	x	x	x	x
06GBH	Hat Hill Creek	Blackheath	19			x	x
07GBH	Popes Glen Creek	Blackheath	22				x
08GBH	Bridal Veil Creek	Blackheath	20				x

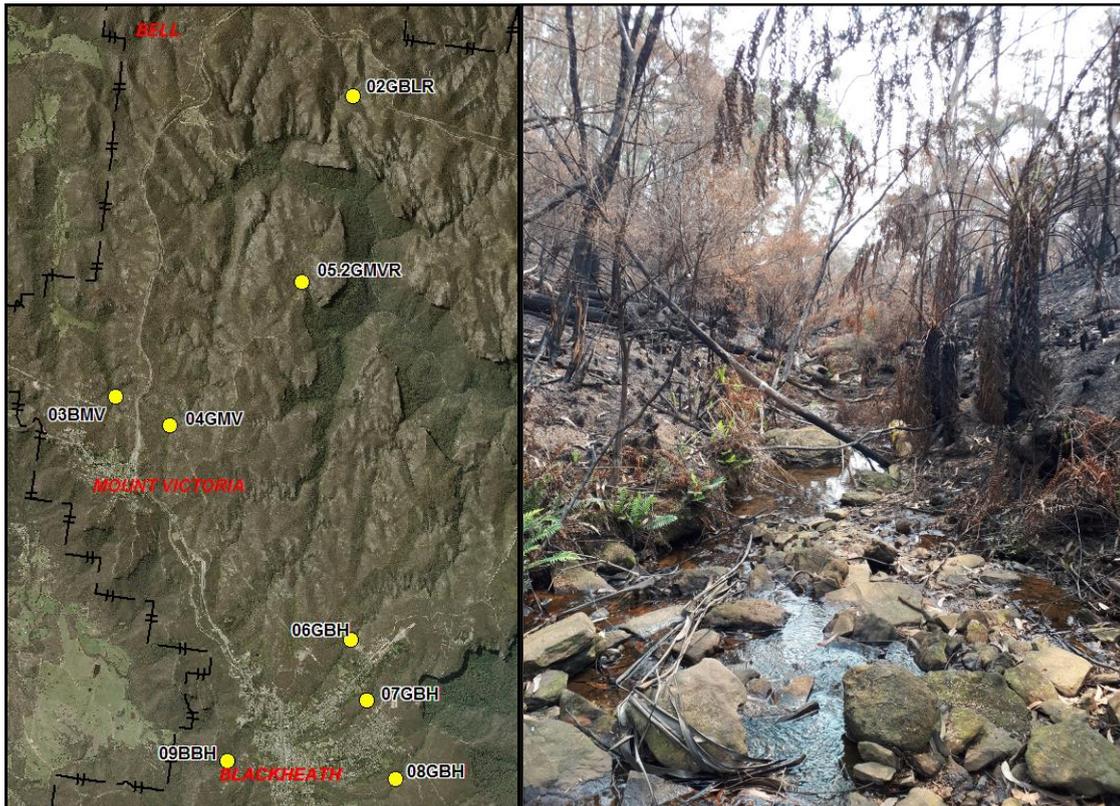


Figure 1(left). Map of focus sites. Two of the sites mapped are not included in analysis- 09BBH as it was not burnt in the 2019-20 fires, and 03BMV, as it was not included in extra sampling due to time constraints. Figure 2 (right). Example photo of burnt site, 07GBH (Pope's Glen Creek), on 15/1/2020.

### *Aquatic macroinvertebrate sampling*

Sampling of macroinvertebrates is based on the AUSRIVAS protocol for collecting and processing samples in NSW (DEC, 2004). A 0.25mm mesh net is used to sample 10 metres of edge habitat within a pre-determined 100 metres of reach at each site. "Edge habitat" includes trailing vegetation, overhanging banks/bedrock/boulders, submerged logs, detritus and aquatic plants.

Two field operators "pick" samples live on site for 40-60 minutes per sample per site. Invertebrates that are accurately identifiable to family level in the field are recorded and released; others are preserved in ethanol for laboratory identification.

Scientific keys are used to identify laboratory specimens, with most taxa identified to family level (Gooderham and Tsyrlin, 2002; The Waterbug Company, 2016; Murray-Darling Freshwater Research Centre, 2015; Dean et al 2004; Hawking and Theischinger, 1999). Binocular stereoscopes are used to examine the distinguishing features of closely related families.

### *Water quality monitoring*

At each site pH, dissolved oxygen (DO), turbidity, temperature, electrical conductivity (EC) and salinity are recorded using a portable multiparameter water quality probe (triplicate readings). The probe currently used is an In Situ AquaTROLL 500, though others have been used in previous years (see BMCC 2018, BMCC 2019). Water samples are collected and analysed in Council's Laboratory for Alkalinity, available Phosphorus, Nitrate-N and Faecal Coliforms, as per test kit manufacturers' instructions.

## Full Paper

### *Blackwood et.al. – Fires, floods, drought, and urban development*

To aid interpretation of water quality results, a series of local trigger values have been developed (adapted from ANZECC, 2000, 7.4.4), using the 95<sup>th</sup>/5<sup>th</sup> percentile values from Blue Mountains reference site data (2010-2015). Separate trigger values are specified for upper (>500m above sea level) and lower (<500m above sea level) mountains sites in recognition of the underlying natural differences in some indicators due to geological variation etc. This system serves as an 'early warning' mechanism, where test results outside of trigger values can indicate potential problems (ANZECC, 2000) (See BMCC 2018 for more detail).

Additional water samples were taken at burnt sites in 2020 to test for a suite of metals, nutrients, cations and anions, dissolved organic carbon, and total organic carbon. These samples were sent to a NATA accredited laboratory for testing. Due to a lack of historical data for these analytes, four unburnt control sites were selected for comparison. Three of these sites were on different upper mountains waterways, with urban catchments, while the fourth site was upstream of 07GBH (Pope's Glen), in an unburnt area.

### *Data analysis*

As part of Council's Waterway Health Monitoring Program, macroinvertebrate data is used to calculate a waterway health rating of Excellent, Fair, Good, Poor or Very Poor. Four factors contribute to this score: SIGNAL-SF (a 'sensitivity' score, see Chessman 2001); number of aquatic macroinvertebrate families present; number of mayfly/stonefly/caddisfly families present (# EPT families); and percentage of individual macroinvertebrates recorded that were mayflies, stoneflies or caddisflies (% EPT). For more information on how this rating is calculated, see the *Blue Mountains Waterway Health Report 2017* (BMCC, 2018).

For the purposes of analysis, samples were grouped into fire history categories of Recent (burnt <7 years ago) or Long (burnt 7 or more years ago). Two sample T-tests (assuming equal variances) were conducted using Excel. These were used to test for differences in key macroinvertebrate statistics between recently burnt and long unburnt samples, and to test for differences in burnt and control sites for the extra water quality parameters.

Multivariate analysis, using PRIMER software, was used to assess and compare the macroinvertebrate community response to fire history. Non-metric multidimensional scaling (nMDS) was performed on a similarity matrix that was calculated with square-root transformed macroinvertebrate data, using the Bray-Curtis dissimilarity measure. The two fire history groups were used to test for macroinvertebrate assemblage differences by one-way analysis of similarity (ANOSIM). In the ordinations, the influence of particular families to ecological differences between test groups was quantified using the similarity percentage procedure (SIMPER).

## Results and discussion

### *Aquatic Macroinvertebrates*

On average, both recently burnt and long unburnt samples received a Waterway Health Score of 'Good', however, there was a significant difference between fire history categories for the numeric health score, and two of its components (#EPT Families, and %EPT), as shown in Table 3. This is a somewhat surprising result, with recently burnt sites scoring as slightly healthier, with more EPT families by both number and proportion.

Multivariate analysis of the macroinvertebrate assemblages adds to this picture. As shown in Figure 1 the two categories form overlapping clusters. ANOSIM reveals a significant difference between the two categories (Global R=0.158, significance 0.1%). This indicates a mild to moderate ecological difference according to fire history. SIMPER analysis found an average dissimilarity of 60.24% between groups, with the three families contributing the most to that dissimilarity being Leptoceridae, Gripopterygidae, and Hydroptilidae (two caddis fly families, and one stone fly family) (see Table 3). These two caddisfly families were more abundant in the recently burnt samples, but the stone fly (Gripopterygidae) was more abundant at long unburnt samples. Five of these top seven families are EPT families, which aligns with the significant differences found in the t tests.

Several reasons for these differences are possible. Leptoceridae and, to a lesser extent, Hydroptilidae, generally construct their cases using leaf and stick detritus. There may be a higher input and availability of this material in the years following fire. Alternatively, the differences may be an artefact of site differences- the less frequently burnt sites are closer to urban areas, and hence more impacted by urban stormwater. It's possible that the differences are driven more by stormwater impacts than by fire history. Further analysis is needed to understand more about the drivers behind these differences. There may be a place for analysis to genus or species level to further understand the ecological changes. Nonetheless, these results do indicate an encouraging level of resilience in these waterways. This data does not reveal any significant negative impacts of fire on these waterways, as could reasonably have been feared.

**Table 2. Key waterway health variables based on aquatic macroinvertebrate data at the seven study sites**

Parameter	Recently Burnt (n=87) Mean (Min-max)	Long Unburnt (n=76) Mean (Min-max)	t-test Significance
# Families	15.13 (5-26)	14.82 (7-22)	Not significant (p=0.573)
# EPT Families	5.11 (1-9)	4.49 (2-7)	Significant (p=0.012)
% EPT	56.79 (13.9-89.6)	50.89 (12.5-89.2)	Significant (p=0.040)
SignalSF	7.26 (6.6-8.1)	7.18 (6.4-8.2)	Not significant (p=0.138)
Waterway Health Score	3.28 (Good) (1.75-4.875) (Poor-Excellent)	3.01 (Good) (1.63-4.75) (Poor-Excellent)	Significant (p=0.012)
Abundance	183.16 (23-722)	154.08 (38-511)	Not significant (p=0.105)

**Table 3. SIMPER analysis results for the first 25% cumulative percentage contribution to dissimilarity**

Species	Recent Average abundance	Long Average abundance	% Contribution	Cumulative Percent
Leptoceridae	2.11	1.67	4.23	4.23
Gripopterygidae	0.82	1.39	4.22	8.46
Hydroptilidae	1.23	0.27	4.09	12.54
Acarina	1.50	0.89	3.87	16.41
Oniscigastridae	0.96	0.17	3.61	20.02
Leptophlebiidae	1.93	1.51	3.44	23.46
Notonectidae	0.98	0.5	3.28	26.74

### Water quality

In the samples taken post-fire throughout 2020, it was more common for some key water quality variables to be outside of the local trigger values, as shown in Table 4. This was most common for Electrical Conductivity (EC), and Dissolved Oxygen (DO), which was often higher than the upper trigger value. Where Alkalinity, Nitrate-Nitrogen and Faecal Coliforms were outside trigger values this was most often for the long-term averages. This indicates that these factors are being driven by longer-term influences, most likely urban stormwater impacts. These apparent changes post-fire may be some of what is driving the changes in the macroinvertebrate community. Further analysis is necessary to investigate this. Other factors could include scouring and erosion from post-fire flooding, changes in temperature, and changes in stream flow due to ongoing catchment hydrology responses to fire.

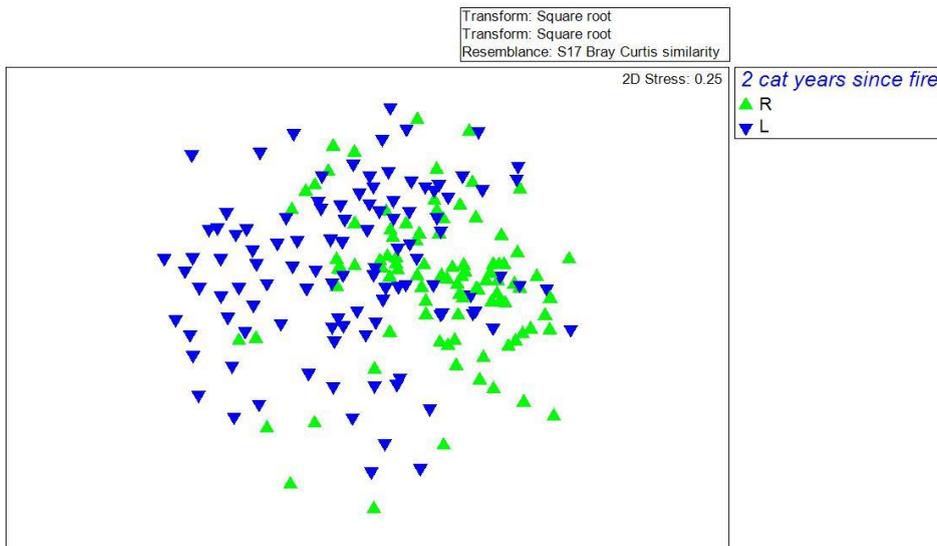


Figure 1. MDS of aquatic macroinvertebrate communities at study sites, grouped by fire category: R (recent, <7 years), and L (long, ≥7years).

Table 4. Key water quality variables at focus sites, showing both long term averages, and averages for 2020. Values that are outside the local trigger values are shaded grey.

Site		EC (us/cm <sup>2</sup> )	pH	DO (%sat)	Turbidity NTU	Alkalinity (ppm CaCO <sub>3</sub> )	Nitrate- nitrogen (mg/L)	Faecal coliforms (CFU/100ml)
<i>Local water quality trigger values for upper Blue Mountains (&gt;500m asl) waterways</i>		<65	4.37-7.24	63.28-100.38	<12.25	<10.9	<0.22	<20
<b>02GBLR Jungaburra</b>	<i>Long term (n=12)</i>	35.9	5.5	70.9	3.5	10.8	0.03	0.7
	<i>2020 (n=1)</i>	53.5	4.9	83.45	0	16	0.02	0
<b>03BMV Fairy Dell</b>	<i>Long term (n=12)</i>	36.3	5.49	71.25	3.9	11.1	0.03	0.6
	<i>2020 (n=1)</i>	175	6.13	100.8	0	6	0.07	0
<b>04GMV Grose Riv. Trib</b>	<i>Long term (n=12)</i>	61.75	6.28	78.1	8.3	12.4	0.235	23.6
	<i>2020 (n=2)</i>	118	5.64	90.6	15.5	11	0.07	150
<b>05.2GMVR Asgard Brook</b>	<i>Long term (n=10)</i>	42.4	5.93	87.3	2.5	5.5	0.06	0
	<i>2020 (n=2)</i>	90	5.2	80.2	0	12.5	0.09	0
<b>06GBH Hat Hill Ck</b>	<i>Long term (n=13)</i>	51.8	6.3	94.8	10.4	7.8	0.11	8.3
	<i>2020 (n=2)</i>	96.7	6.0	105.4	12.17	7.0		0
<b>07GBH Popes Glen Ck</b>	<i>Long term (n=14)</i>	96.5	7.0	90.6	10.2	19.8	0.28	45.4
	<i>2020 (n=2)</i>	136.3	6.5	105.9	30.9	12		20
<b>08GBH Bridal Veil Ck</b>	<i>Long term (n=14)</i>	58.0	7.0	95.6	5.4	9.5	0.39	37.1
	<i>2020 (n=2)</i>	79.5	6.7	113.0	1.0	14.5	0.275	25

The extra water quality sampling revealed only one significant difference between burnt and unburnt control sites. This was for Total Alkalinity as CaCO<sub>3</sub> (mg/L) (Burnt 6.11, Unburnt 11.6, p<0.05). This is most likely a reflection of the catchments of the sites, as the control sites do have larger urban catchments. Given the hugely extensive nature of the 2019-20 bushfires, this was difficult to avoid, as most waterways with less urban catchments in this part of the upper Blue Mountains were burnt. Hence it was difficult to find more equivalent control sites. For all other variables tested there was either no significant difference (Suspended solids, Sulfate, Chloride, Calcium, Magnesium, Sodium, Potassium, Zinc, Ammonia, Nitrogen, Anions, Cations,

## **Full Paper**

*Blackwood et.al. – Fires, floods, drought, and urban development*

Dissolved Organic Carbon and Total Organic Carbon), fewer than five detections (Cadmium, Copper, Nickel, Lead, Phosphorous), or no detections (Arsenic, Chromium, Mercury).

It is possible that the frequency of sampling was insufficient to detect pulses of inputs post-fire, and that impacts were exported downstream, given that all sites are located on headwater streams. Nonetheless, the lack of significant detected negative impacts shows a level of resilience in the study streams. It is important to note that like many upper Blue Mountains waterways, these creeks and their tributaries are fed by a steady flow of high quality groundwater. Elsewhere it has been hypothesized that these groundwater inputs help to offset prevailing urban impacts and support a relatively sensitive and diverse array of macroinvertebrates, compared to other creeks in the Sydney region (Wright et al. 2007). It may be possible that the groundwater inputs are playing a similarly protective role when it comes to fire impacts.

## **Conclusions and Management Implications**

This research contributes new knowledge that helps improve our understanding about the impact of bushfires on Blue Mountains streams. This is of heightened concern as the IUCN (2020) Conservation Outlook Assessment downgraded the status of the GBMA to 'Significant Concern'. Driving this was concern by IUCN that climate change and uncontrollable wildfire was a 'very high threat' throughout the GBMA and surrounding lands. This research is underpinned by more than 20 years of monitoring of water quality and aquatic invertebrates at a large number of sites across the Blue Mountains area by Blue Mountains City Council. This monitoring encompasses sites of varying altitude, stream size, and from different land uses.

The results from this research showed that the stream invertebrate communities displayed a much higher degree of resilience to bushfire than was expected. These results even suggested that some measures of stream ecological health (see Table 2) were higher at more recently burnt sites. Although more research is needed, these results differ from other similar Australian bushfire research where recently burnt sites had much lower taxonomic richness than unburnt sites (Verkaik et al. 2013). Perhaps the stream invertebrates of the highly bushfire-prone Blue Mountains are well adapted to varying intensity and regularity of bushfires, with stream biodiversity increasing, possibly reflecting the 'intermediate disturbance hypothesis' (Connell, 1978)? This hypothesis suggests that occasional intense natural disturbances can increase biodiversity through increased competition through displacing dominant species. Further research is needed on this topic to help guide adaptive management of streams and surrounding ecosystems in the Blue Mountains.

While results indicate a heartening level of resilience in study streams, it is still important to manage catchments and waterways to build and maintain resilience. The IUCN state that "Recovery from the 2019/20 fires will need to continue being undertaken with a view to building ecosystem resilience in the face of continued drought and catastrophic fire conditions" (2020). Disturbances such as drought, extreme heat, floods and fires are predicted to increase under global heating conditions. One key area in the power of land managers to build resilience is in managing the impacts of urban stormwater through Water Sensitive Urban Design (WSUD). Council is working towards building this resilience through strategic initiatives such as the Blue Mountains Water Sensitive Strategic Plan (2019). While much work to implement this plan remains to be done, capacity for WSUD initiatives has been developing within Council teams in the past decade. This enabled rapid response projects to be initiated post bushfire, to construct erosion prevention and stormwater devices at key fire-affected stormwater outlets. Further analysis of waterway health data will better inform such work in the future.

This work emphasizes the value of long term monitoring programs such as Council's Waterway Health Monitoring Program. Programs such as this provide vital contributions to our understanding of waterway health, and build capacity for adaptive management. Unfortunately, programs such as this are rare, particularly in NSW. If similar programs can be established in other areas this would allow for comparative analysis to be conducted, and for further analysis to investigate the mechanisms behind the response of macroinvertebrate communities to fire.

## **Acknowledgments**

This work was conducted within the Country of the Darug and Gundungurra peoples. The authors recognise that Darug and Gundungurra Traditional Owners have a continuous and deep connection to their Country and that this is of great cultural significance to Aboriginal people, both locally and in the region. For Darug and Gundungurra People, Ngurra (Country) takes in everything within the physical, cultural and spiritual landscape—landforms, waters, air, trees, rocks, plants, animals, foods, medicines, minerals, stories and special places. It includes cultural practice, kinship, knowledge, songs, stories and art, as well as spiritual beings, and people: past, present and future. The authors pay respect to Elders past and present, while recognising the strength, capacity and resilience of past and present Aboriginal and Torres Strait Islander people in the Blue Mountains region.

We thank the editors and acknowledge the work of past and present staff and volunteers who have contributed to the Waterway Health Monitoring Program, including Christina Day and Cecil Ellis. We are grateful to John Gooderham, who, as well as providing generous advice when needed, designed the first version of an Access database for the macroinvertebrate data, allowing for easier analysis of a large dataset.

## **References**

- Blue Mountains City Council (BMCC), (2018). *Blue Mountains Waterways Health Report 2017*. Blue Mountains City Council, Katoomba.
- Blue Mountains City Council (BMCC), (2019). *Blue Mountains Waterways Health Report 2019*. Blue Mountains City Council, Katoomba.
- Blue Mountains City Council (BMCC) (2019). *Water Sensitive Blue Mountains Strategic Plan*. Blue Mountains City Council, Katoomba.
- Chessman, B. (2001) *SIGNAL2: A Scoring System for Macro-invertebrates ('Water Bugs') in Australian Rivers—User Manual Version 2*
- Connell, J.H. (1978) Diversity in Tropical Rain Forests and Coral Reefs. *Science*, 24 Mar 1978, Vol. 199, Issue 4335, pp. 1302-1310
- Dean, J., St Clair, R. and Cartwright, D. (2004) *Identification keys to Australian families and genera of Caddis-fly larvae (Trichoptera)*, Co-operative Research Centre for Freshwater Ecology, Albury.
- Department of Environment and Conservation (DEC) NSW, (2004) *New South Wales (NSW) Australian River Assessment System (AUSRIVAS) Sampling and Processing Manual*, DEC, Sydney
- Department of Planning, Industry and Environment (DPIE)(2010), *NPWS Fire History - Wildfires and Prescribed Burns (SEED map)*, accessed 29/4/21 <https://datasets.seed.nsw.gov.au/dataset/fire-history-wildfires-and-prescribed-burns-1e8b6>
- Gooderham, J. and Tsyrlin, E. (2002) *The Waterbug Book*, CSIRO Publishing, Melbourne.
- Hawking, J. and Theischinger, G., (1999) *Dragonfly Larvae (Odonata): A guide to the identification of larvae of Australian families and to the identification and ecology of larvae from NSW*, Murray-Darling Freshwater Research Centre, Albury.
- International Union for the Conservation of Nature (IUCN) (2020) *Greater Blue Mountains Area 2020 Conservation Outlook Assessment*, accessed 1/3/2021 <https://worldheritageoutlook.iucn.org/node/1104>
- Murray-Darling Freshwater Research Centre, (2015) *Online guide for the identification and ecology of Australian freshwater invertebrates*, Murray-Darling Freshwater Research Centre. Available at: <http://www.mdfrc.org.au/bugguide/>
- Verkaik I., Prat N., Rieradevall M., Reich P., Lake P. S. (2013) Effects of bushfire on macroinvertebrate communities in south-east Australian streams affected by a megadrought. *Marine and Freshwater Research* 65, 359-369.
- Waterbug Company (2016) *The Waterbug App*, The Waterbug Company, Hobart. Available at: <http://thewaterbugapp.com/>
- Wright, I., Davies, P., Wilks, D., Findlay, S. and Taylor, P. (2007), 'Aquatic macroinvertebrates in urban waterways: comparing ecosystem health in natural reference and urban streams', in Wilson, A.L., Dehaan, R.L., Watts, R.J., Page, K.J., Bowmer, K.H. and Curtis, A. 2007, *Proceedings of the 5th Australian Stream Management Conference. Australian rivers: making a difference*. Charles Sturt University, Thurgoona, NSW.