Bifenthrin pesticide contamination: impacts and recovery at Jamison Creek, Wentworth Falls.

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Key Points

- Jamison Creek in the Blue Mountains was contaminated by a pesticide, Bifenthrin, in July 2012
- The pesticide caused a mass crayfish kill and severe, adverse effects on aquatic macroinvertebrates
- Eighteen months later, the macroinvertebrate community (including crayfish) has recovered well
- The incident highlights the potential hazards of urban pesticide use and the risks associated with direct stormwater connections between urban areas and natural waterways

Abstract

In July 2012, over 1000 dead Giant Spiny Crayfish (*Euastacus spinifer*) were found in a two kilometre reach of Jamison Creek, Wentworth Falls, including within the Greater Blue Mountains World Heritage Area. A multi-agency investigation discovered the crayfish were killed by a termiticide, Bifenthrin, and that the effects extended beyond the crayfish to the entire aquatic macroinvertebrate community. The contaminant entered the creek via a conventional stormwater drainage system of pits and pipes, which provided a direct connection between the property at which the pesticide was over-applied and the creek 300m away. The pest control operators involved were prosecuted.

Initial impacts were catastrophic, with most aquatic macroinvertebrate families previously recorded at the creek (pre-incident average of 17 families including 5 sensitive Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa) absent from the July 2012 (post-incident) survey. In the eighteen months since the contamination, steady improvements in aquatic macroinvertebrate diversity and abundance have been observed (now similar to pre-incident results) and *E. spinifer* have recolonised the creek.

Factors believed to have assisted recovery include the presence of good-condition, pesticide-unaffected tributary streams, allowing for rapid re-recruitment into the main trunk of Jamison Creek. Inputs to the creek and its tributaries of high quality groundwater (via Blue Mountains Swamps) are also believed to have offset ongoing urban impacts and facilitated the re-establishment of a 'healthy' assemblage of aquatic biodiversity.

As well as having implications for the pest control industry and its regulators, the incident demonstrates the dangers of having urban areas directly connected to natural waterways via conventional stormwater infrastructure (i.e. catchments with high levels of effective imperviousness) and highlights the importance of best practice water sensitive urban design, stormwater management, planning controls and related education as protection for waterways.

Keywords

Bifenthrin, pesticide, contamination, freshwater crayfish, aquatic macroinvertebrates, effective imperviousness, recovery, Jamison Creek, Wentworth Falls, Blue Mountains

Introduction

In the Blue Mountains of New South Wales, around 80,000 people live in a string of ridge top townships, many within Sydney's drinking water catchments, and surrounded by World Heritage listed National Park. Urban impact on freshwater streams in the area was identified as an issue of concern during the nomination and listing for World Heritage status (Commonwealth Government, 1998), and while many of the region's waterways are considered to be of high conservation value, the threats posed by urban development remain (Blue Mountains City Council, 2014).

In July 2012, over 1000 dead Giant Spiny Crayfish (*Euastacus spinifer*) were found in Jamison Creek, Wentworth Falls (870m above sea level), a waterway that ultimately flows to Sydney's drinking water supply, Warragamba Dam. The carcasses were observed to cover more than a two kilometre reach, spanning both Blue Mountains City Council (BMCC) and World Heritage listed Blue Mountains National Park land.

A multi-agency investigation (involving BMCC, the NSW Environment Protection Authority (EPA), the NSW Office of Environment and Heritage (OEH), the NSW Department of Primary Industries (DPI) and others) found that a pesticide, Bifenthrin, caused the crayfish deaths. The source of the contamination was determined by testing sediment and water samples and in September 2013 two defendants (pest control operators – one company and one individual) pleaded guilty in Katoomba Local Court to water pollution offences under Section 120 of the *Protection of the Environment Operations Act 1997*. During the treatment of a medium density residential development in Wentworth Falls (on 5 July 2012), the pest controllers over-applied Bifenthrin by approximately 53%. The pesticide reticulation pipe was located within one metre of a stormwater pit that connected, via a series of pits and pipes, to the creek 300m away. On 6 July 2012 there was a light rainfall (approximately 3mm) and the mass crayfish kill was discovered the following day.

Bifenthrin is an insecticide used for the control of termites and borers in timber, insect pests in agricultural crops and turf, and for general pest control (spiders, ants, fleas, flies and mosquitos) (Australian Pesticides and Veterinary Medicines Authority, 2008). A third generation synthetic pyrethroid, it has low water solubility but binds strongly to sediment and has a relatively long environmental persistence time (field dissipation half-life up to 345 days). It is extremely toxic to terrestrial and aquatic insects, crustaceans and fish, disabling the central and peripheral nervous systems by interfering with the sodium channels (Johnson et al. 2010). It is more toxic to aquatic than terrestrial organisms because it inhibits enzymes required for osmoregulation and the maintenance of ionic balances in an aquatic environment, and is readily absorbed by gilled animals (Boyd et al. 2002).

Two species of freshwater crayfish, *Euastacus spinifer* (Heller 1865) and *Euastacus australasiensis* (Milne Edwards 1837) are endemic in the region. *Euastacus spinifer* is placed within the giant spiny crayfish group and can attain a size of 116 mm occipital carapace length (OCL) and weight of 1000 grams (McCormack 2012).

This is a keystone species, its abundance directly affecting the success of numerous other animals including macroinvertebrates, fish, eels, turtles, lizards, snakes, water rats, platypus and birds. Of any 5,000 juvenile crayfish released each year, only one may survive the seven plus years to become an adult, the others having nourished many other species in the catchment (McCormack, in preparation).

Euastacus australasiensis is an intermediate group crayfish, reaching a size of up to 75mm OCL and 215g (McCormack 2012). Whereas *E. spinifer* is restricted to permanent streams and prefers its burrow flooded with stream water (making it vulnerable to water pollution), *E. australasiensis* tends to inhabit smaller streams, swamps and seepages, with much of the burrow system unflooded.

The translocated invasive yabby *Cherax destructor* has been recorded in other parts of the region and an initial concern was that the mass kill of *E. spinifer* may enable the faster growing and breeding invasive crayfish to replace the endemic species, as has occurred elsewhere (McCormack, 2014 in press).

Extending beyond the effects on freshwater crayfish, the Bifenthrin contamination had a significant impact on the entire aquatic macroinvertebrate community of Jamison Creek. Funded by a local Environment Levy, Blue Mountains City Council conducts annual water quality and aquatic macroinvertebrate monitoring at over fifty waterways throughout the local government area. One of these sites ('Weeping Rock') is on Jamison Creek, approximately two kilometres downstream from the Bifenthrin entry point. Prior to the pesticide contamination, data was collected for five consecutive years (2008-2012) at this site. An additional three years' worth of data (2005-2007) was available for a different site ('Armstrong St'), approximately 560m downstream of the pesticide entry point. In the aftermath of the pollution incident, two new monitoring sites were established: one ('Behind Shops') upstream and one ('Darwin Bridge') 120m downstream of the point of Bifenthrin contamination. More frequent sampling was implemented to track the recovery of the aquatic macroinvertebrate community at the creek and separate freshwater crayfish surveys were conducted 9 months post contamination.

Field sites and methods

Table 1. Overview of data types, numbers of sites and samples, provenance and timeframes

Type of data collection	# Sites (# samples)	Performed by	Period of data collection
Macroinvertebrate Sampling	4 (29)	BMCC	Mar 2005 – Jan 2014
Water Quality Monitoring	4 (66)	BMCC	Mar 2005 – Jan 2014
Freshwater Crayfish Surveys	3 (30)	R. McCormack	Jul 2012- Apr 2014

Bifenthrin testing	8 (19)	OEH	Jul 2012
Data analysis	n/a	I. Wright & BMCC	2014

Aquatic Macroinvertebrate Sampling

Prior to Bifenthrin contamination, Jamison Creek was sampled on eight occasions between March 2005 and March 2012 (at Armstrong St from 2005-07 and at Weeping Rock from 2008-12). Weeping Rock (2200m downstream of Bifenthrin entry point) continued to be sampled following the incident, along with two new sites: 'Behind Shops' (290m upstream of Bifenthrin entry point) and 'Darwin Bridge' (120m downstream of Bifenthrin entry point). These three sites were sampled at approximately monthly intervals in the period from July to November 2012, then at three other times (9 months, 12 months and 20 months) post-contamination. See figure 1 for an illustration of site locations.

Sampling of macroinvertebrates was based on the AUSRIVAS protocol for collecting and processing samples in NSW (Department of Environment and Conservation, 2004). On each occasion at each site, ten metres of 'edge' habitat was sampled using a 0.25mm mesh size net. Two field operators picked samples live on site, for a minimum of 40 minutes per site. Taxa that were accurately identifiable to family level in the field were recorded and released; all other specimens were preserved in alcohol for identification to family level (where possible) in Council's laboratory, using scientific keys.

A range of biotic indices were calculated from aquatic macroinvertebrate results, including SIGNAL-SF (Chessman, et. al. 2007; Chessman, 2001); taxonomic richness; mayfly, stonefly and caddisfly (EPT) diversity; and abundance (Wright et al. 2007).

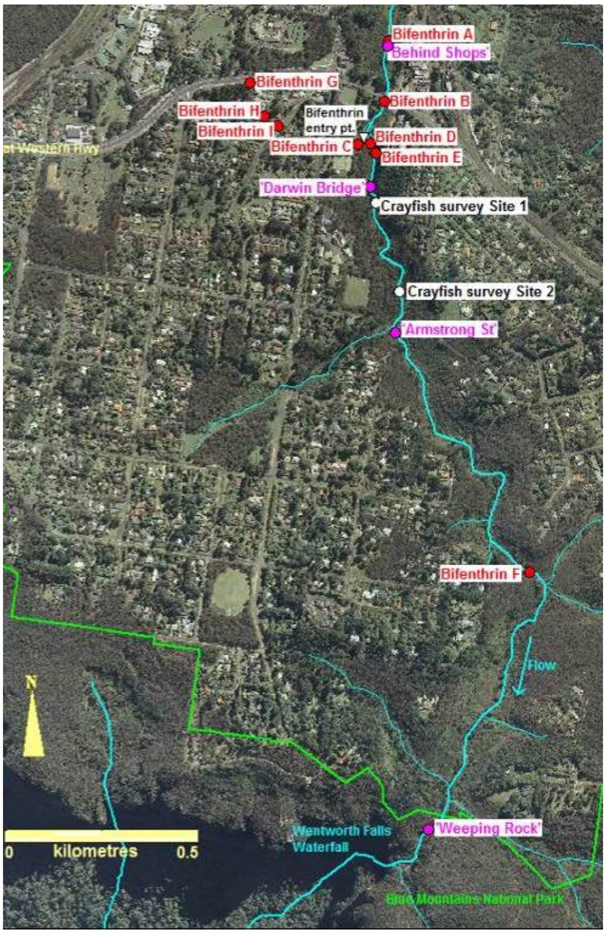


Figure 1 (left). Map of Jamison Creek showing sampling locations. Figure 2 (right). BMCC & DPI staff inspect dead crayfish at Jamison Creek.

For the purposes of data analysis, macroinvertebrate samples were divided into three categories: 'reference' (from one site upstream of contamination and two sites downstream prior to contamination), 'impact' (from two sites downstream of contamination, in July, August and September 2012) and 'recovery' (from the same two sites downstream of contamination, in November 2012 to January 2014). A one-way analysis of variance (ANOVA) was used to investigate whether macroinvertebrate biotic indices (SIGNAL SF, taxonomic richness, abundance) varied according to test category (reference, impact or recovery).

Multivariate analysis, using the PRIMER software, was used to assess and compare the macroinvertebrate community response to catchment and waterway disturbance. 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. Data were grouped (reference, impact or recovery), 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).

Water Quality Monitoring

pH, dissolved oxygen, temperature, electrical conductivity and salinity were measure in-situ with a calibrated Hydrolab Quanta probe. Triplicate samples were measured from March 2012 to January 2014; single samples only were measured on sampling occasions prior to March 2012.

Freshwater Crayfish Surveys

Freshwater crayfish surveys were undertaken on 13 April 2013 (9 months post pesticide contamination) at two sites on Jamison Creek and one site on Leura Falls Creek (a nearby, similar waterway, unaffected by the Bifenthrin contamination incident). At each site five opera house and five box traps were set consecutively, approximately five metres apart, baited with fresh fish and left for approximately three hours. Most animals were identified and released at the collection site, with some voucher material retained where appropriate.

Testing for Bifenthrin

Samples were tested for Bifenthrin by the Office of Environment and Heritage Laboratory, Lidcombe, NSW. Biota (crayfish) samples were extracted using the QuEChERs method (Anastassiades, 2011), liquid samples were extracted with dichloromethane and solid samples were extracted with acetone, dichloromethane and hexane using an accelerated solvent extractor. All extracts were then analysed using Gas Chromatography/ Mass Spectrometry.

Results and Discussion

Aquatic Macroinvertebrates

A total of 2330 macroinvertebrates were collected from 29 samples at four sampling sites in Jamison Creek, from March 2005 to January 2014. Macroinvertebrate communities were significantly, adversely affected by the Bifenthrin contamination. Summary macroinvertebrate statistics (Table 2) show that abundance of invertebrates changed significantly in Jamison Creek (F=7.03, p=0.004) after contamination, dropping from a mean of 100.6 to 13 animals per sample for the three month period following the incident. Eighteen months post-contamination, abundance has returned to near pre-incident levels (mean 92.9 animals per sample). Taxonomic richness changed similarly (F=7.03, p<0.0001), dropping from a mean of 14.7 families per sample to 3.7 families per sample following the contamination. Again the taxonomic richness of Jamison Creek has returned to near pre-incident levels (mean 13.6 families per sample). The SIGNAL-SF biotic index was also significantly lower (mean 5.9) following the incident (F=4.5, p=0.021), compared to other samples from Jamison Creek (mean 6.5). SIGNAL-SF scores have since returned to levels (mean 6.3) comparable to pre-contamination results. Figure 3 graphs the number of families and the number of EPT families recorded at the two downstream sites over time.

Samples collected downstream of the contamination during July, August and September 2012 had a modified macroinvertebrate community structure, compared to all other Jamison Creek samples. The nMDS plot (Figure 4) shows that the 6 macroinvertebrate samples collected downstream during this period are positioned well separated from the cluster of all other Jamison Creek samples. The relative distance of these samples away from the other clump of samples represents ecological distance due to a loss of macroinvertebrate groups normally found in Jamison Creek. ANOSIM results (Table 3) confirm that these 6 samples are statistically distinct from the others, with an R statistic of 0.834 (and very high significance). The most recent samples downstream from the Bifenthrin entry point have revealed a community structure very similar to that recorded prior to the contamination (with an R statistic of 0.162, not significant).

Table 2. Summary of Aquatic Macroinvertebrate Results

Site/sample grouping	SIGNAL-SF score	# families	# EPT families	Total abundance	% EPT
Reference*					
Mean (n)	6.5 (15)	14.7 (15)	3.5 (15)	100.6 (15)	31.5 (15)
Range (min-max)	5.8-7.1	7-22	1-6	29-208	1.7-59.8
Impact* *One-way ANOVA (compared to Ref)*	*F=4.5, p=0.021*	*F=7.03,p=0.0001*		*F=7.03, p=0.004*	
Mean (n)	5.9 (6)	3.7 (6)	0.3 (6)	13.0 (6)	2.8 (6)
Range (min-max)	5.0-6.5	1-8	0-1	3-33	0.0-10.5
Recovery*					
Mean (n)	6.3 (8)	13.6 (8)	2.9 (8)	92.9 (8)	19.1 (8)
Range (min-max)	5.8-6.8	7-20	1-5	19-187	1.9-40.6
* 'Reference' samples are from the 'Behind Shops' site as well as 'Weeping Rock' and 'Armstrong St' prior to Bifenthrin contamination. 'Impact' samples are from 'Weeping Rock' and 'Darwin Bridge' in Jul-Sep 2012. 'Recovery' samples are from 'Weeping Rock' and 'Darwin Bridge' in Nov2012-Jan2014.					

The SIMPER procedure assessed the type and abundance of macroinvertebrates that contributed to the degraded ecological condition detected at the two sampling sites impacted by the contamination (Table 4). The most numerically influential four families were Chironomidae (midge), Gripopterygidae (stonefly), Leptoceridae (caddisfly)and Acarina (watermite) all of which were normally plentiful in Jamison Creek but were far less numerous or absent in the 3 months after contamination.

The macroinvertebrate results collected since November 2012 confirm that an ecological recovery of Jamison Creek has taken place. The most recent samples show that the macroinvertebrate community structure is very similar to that in Jamison Creek prior to or upstream of the spill. This is confirmed by the ANOSIM pairwise comparison (Table 3) between 'reference' samples and 'recovery' samples (R-value of 0.162, p=0.056). Two highly sensitive families, Leptoceridae (caddisfly) and Leptophlebiidae (mayfly) that were absent or rare in the months following contamination (Table 4) have returned to abundance levels similar to those recorded prior to the incident. The previously numerous stonefly larvae (Gripoteryigidae) has yet to return to levels of abundance recorded prior to Bifenthrin contamination (Table 4).

The rapid recovery of the aquatic macroinvertebrate community is thought to have been aided by the presence of good-quality, pesticide unaffected tributaries (allowing direct recolonisation into the main trunk of the creek). Like many upper Blue Mountains waterways, Jamison Creek and its tributaries are fed by a steady flow of high quality groundwater (BMCC, 2009), which helps 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).

Table 3. Extent and significance of ecological differences in macroinvertebrate samples (ANOSIM R statistics and p-values) for pairwise comparisons of reference, impact and recovery samples.

Pairwise comparison	R Statistic	Significance level (%)
Reference* samples vs. impact* samples	0.867	0.1
Reference samples vs. recovery* samples	0.162	5.6
Impact samples vs. recovery samples	0.547	0.2
* 'Reference' samples are from the 'Behind Shops' site as well as 'Weeping Rock' and 'Armstrong St' prior to Bifenthrin contamination. 'Impact' samples are from 'Weeping Rock' and 'Darwin Bridge' in Jul-Sep 2012. 'Recovery' samples are from 'Weeping Rock' and 'Darwin Bridge' in Nov2012-Jan2014.		

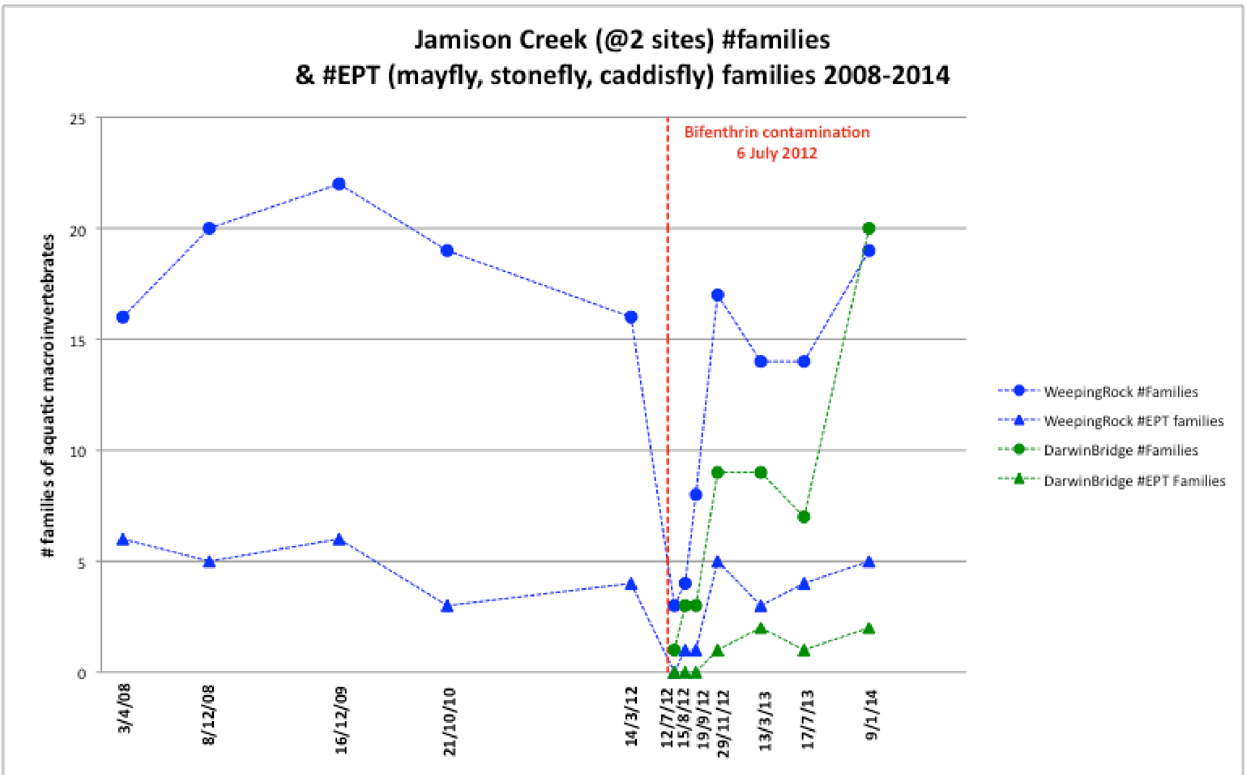
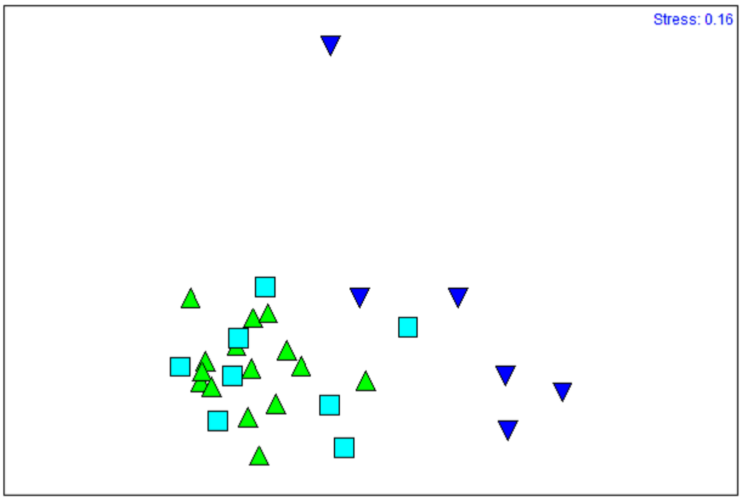


Figure 3. Biplot showing the number of families of aquatic macroinvertebrates and the number of EPT families recorded at the Weeping Rock and Darwin Bridge sites over time.

Table 4. Summary of Aquatic Macroinvertebrate Results. Mean abundance (per sample) of the most numerically influential families (according to SIMPER analysis) in Jamison Creek. This compares mean abundance (per sample) between reference, impact and recovery samples.

Families	Reference samples*	Impact samples*	Recovery samples*
Chironomidae	18.0	6.67	33.5
Gripopterygidae	18.67	0.33	3.75
Leptoceridae	9.53	0	11.63
Acarina	10.3	0.5	5.25
Veliidae	8.5	0	5.75
Corixidae	6.4	0	0.38
Simuliidae	3.7	0	4.75
Oligochaeta	1.47	3	1.88
Megapodagrionidae	0.6	0.33	3.63
Leptophlebiidae	2.7	0	3.63
Parastacidae	2.8	0	0.75
Telephlebiidae	1.7	0	3

* 'Reference' samples are from the 'Behind Shops' site as well as 'Weeping Rock' and 'Armstrong St' prior to Bifenthrin contamination. 'Impact' samples are from 'Weeping Rock' and 'Darwin Bridge' in Jul-Sep 2012. 'Recovery' samples are from 'Weeping Rock' and 'Darwin Bridge' in Nov2012-Jan2014.



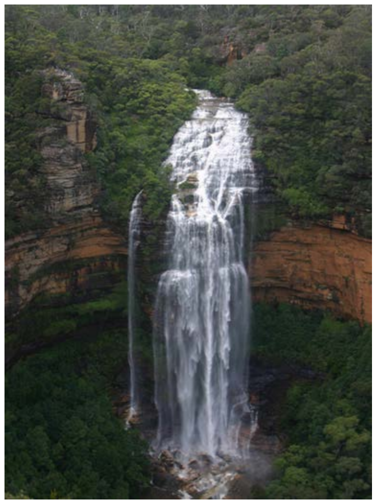


Figure 4 (left). NMDS ordination of Jamison Creek macroinvertebrate data 2005-2014. Stress = 0.16. Each symbol represents a macroinvertebrate sample. 'Reference' samples (upstream of or prior to contamination) are upward green triangles, 'impact' samples (downstream of contamination in July, August and September 2012) are downward dark blue triangles and 'recovery' samples (downstream of contamination in November 2012 to January 2014) are light blue squares.

Figure 5 (right). Wentworth Falls waterfall, Jamison Creek (approximately 150m downstream of the Weeping Rock site, and 2350m downstream of the Bifenthrin entry point).

Water Quality Monitoring

Table 5. Summary of Water Quality Monitoring Results

Site/Sample grouping	pH	Turbidity (NTU)	Dissolved Oxygen (% saturation)	Temp (^{0}C)	Electrical Conductivity (us/cm)
Reference*					
Mean (n)	7.03 (27)	9.51 (27)	75.38 (25)	15.21 (27)	60.00 (27)
Range (min-max)	6.00-7.50	2.30-15.20	50.50-110.90	8.48-22.79	50.00-90.00
Impact*					
Mean (n)	7.11 (15)	11.05 (15)	80.03 (15)	8.61 (15)	60.00 (15)
Range (min-max)	6.89-7.45	6.10-15.90	71.20-85.00	7.06-11.52	50.00-90.00
Recovery					
Mean (n)	7.25 (24)	10.15 (24)	85.48 (24)	14.64 (24)	60.00 (24)
Range (min-max)	6.78-7.63	6.00-17.10	65.50-95.60	9.75-19.66	60.00-90.00
Local low-risk trigger values (BMCC, 2014; ANZECC, 2000)**	5.18-7.07	9.8	73.14	n/a	54.00

* 'Reference' samples are from the 'Behind Shops' site as well as 'Weeping Rock' and 'Armstrong St' prior to Bifenthrin contamination. 'Impact' samples are from 'Weeping Rock' and 'Darwin Bridge' in Jul-Sep 2012. 'Recovery' samples are from 'Weeping Rock' and 'Darwin Bridge' in Nov2012-Jan2014. **Based on 80th/20th percentile values from pristine Blue Mountains reference sites (n=25).

Freshwater Crayfish Surveys

Only *Euastacus spinifer* was recorded at Jamison Creek during the pollution event and in subsequent surveys. This is unusual, as most of the streams in the region have *E. australasiensis* as the dominant species at the top of the catchment and it is only further downstream that *E. spinifer* occurs (McCormack, 2013). At Leura Falls Creek, a nearby creek with similar characteristics, only *E. australasiensis* was recorded. The results observed at Jamison Creek nine months after the pollution event showed an abundant population of *E. spinifer* (McCormack, 2013), with the animals presumed to have relocated into the main trunk of the creek from unaffected tributaries. No evidence of the invasive species *Cherax destructor* was recorded. Healthy populations of two native fish species were also observed: *Galaxias olidus* (Mountain Galaxias) and *Retropinna semoni* (Australian Smelt) (McCormack, 2013).

The *E. spinifer* individuals recorded at Jamison Creek in April 2013 were significantly smaller than the maximum sizes expected for the species (McCormack, 2012). The mean OCL recorded during the survey was 44% of the expected maximum and the mean weight recorded during the survey was 6% of the expected maximum. This suggests that the creek has been recolonized by immature crayfish, and that the mature individuals may have been removed by the pollution incident. Considering that *E. spinifer* does not reach sexual maturity until the age of 7-9 years (McCormack, 2012), it is possible that the incident may have longer-term effects on the crayfish population of Jamison Creek.

Table 6. Results of Freshwater Crayfish Surveys

Site name	Crayfish captured	Mean cray size	Fish captured
Crayfish Survey Site 1 (Jamison Creek)	14 *Euastacus spinifer* (Giant Spiny Crayfish)	OCL* = 56mm Weight = 86g	2 *Galaxias olidus*
Crayfish Survey Site 2 (Jamison Creek)	5 *Euastacus spinifer* (Giant Spiny Crayfish)	OCL = 46mm Weight = 42g	69 *Galaxias olidus* 12 *Retropinna semoni*
Crayfish Survey Site 3 (Leura Falls Creek)	22 *Euastacus australasiensis* (Sydney Crayfish)	OCL = 46mm Weight = 55g	No fish captured
*OCL = Occipital Carapace Length			

Bifenthrin

Table 7. Bifenthrin levels in water and sediment samples collected during investigation into source

Site type	Sample code on map	Date of sample (#days post spill)	Bifenthrin (ug/L) in sediment sample	Bifenthrin (ug/L) in water sample	Bifenthrin (ug/L) in crayfish sample
Creek	-	10/7/12 (4)	-	-	120*
Creek	-	13/7/12 (7)	-	0.02*	39*
Creek	Bifenthrin A	18/7/12 (12)	36	<0.2	-
Creek	Bifenthrin B	18/7/12 (12)	<18	<0.2	-
Stormwater outlet	Bifenthrin C	18/7/12 (12)	9800	0.6	-
Creek	Bifenthrin D	18/7/12 (12)	-	<0.2	-
Creek	Bifenthrin E	18/7/12 (12)	7.2	<0.2	-
Creek	Bifenthrin F	18/7/12 (12)	30	<0.2	-
Stormwater pit	Bifenthrin G	25/7/12 (12)	<6	-	-
Private detention basin	Bifenthrin H	25/7/12 (19)	130,000	4.7	-
Stormwater pit	Bifenthrin I	25/7/12 (19)	500	3.8	-
***** Estimated concentration (below the method practical quantification limit)					

The above results reflect Bifenthrin's tendency to bind strongly to sediment, with high levels found in some sediment samples corresponding with much lower levels in water samples. Although Bifenthrin levels were not measured in the early stages of the incident, observed impacts on crayfish and other macroinvertebrates suggest levels were above toxicity thresholds for most macroinvertebrate groups. Some guidance on approximate toxicity thresholds is provided by a Californian study that quantifies the Lethal Concentration, 50% (LC50) for a range of aquatic macroinvertebrates, including a species of Amphipod from the Hyalellid family (LC50 = 0.009ug/L Bifenthrin), a species of Mayfly from the Baetid family (LC50 = 0.08ug/L Bifenthrin) and a species of Midge from the Chironomid family (LC50 = 26ug/L Bifenthrin) (Anderson et al. 2006).

The very high levels found in sediment in the private stormwater detention basin (sample code Bifenthrin H) confirmed the source property and prompted an urgent clean out of the stormwater system to prevent further contamination of Jamison Creek.

The level of Bifenthrin detected in sample code Bifenthrin A is concerning, as this site is 290m upstream of the point at which the pesticide entered during the July 2012 incident. The result suggests a separate Bifenthrin contamination incident (with no reported fish or crayfish kills) from a different part of the Jamison Creek catchment and raises questions about how frequently this pesticide is polluting natural waterways.

One of the underlying causes of the Jamison Creek contamination is the nature of the stormwater system draining the sub-catchment in which the incident occurred. This sub-catchment is characterised by a high level of connected imperviousness (approximately 50% of the 3 hectare sub-catchment is covered by impervious surfaces that are directly connected to the creek by conventional stormwater pits and pipes). This direct connection facilitated the contamination of the creek, by carrying the pesticide efficiently from the urban environment straight into the natural waterway (a distance of approximately 300m).

The link between connected or effective imperviousness of catchments and the health of receiving waterways has been well established in Australian research (for example Burns et al. 2012; Davies et al. 2010; Tippler et al. 2012; Walsh, 2009; Walsh and Kunapo, 2009; Walsh et al. 2005). In a sub-catchment with a more 'water sensitive' approach – e.g. using rainwater tanks on buildings, rain gardens, swales, bioretention/bioinfiltration systems and other measures to achieve low (or preferably zero) connected imperviousness, opportunities for soil-binding of Bifenthrin would have been greatly increased, with a likely reduction of negative impacts on the creek.

Conclusions

The pesticide contamination of Jamison Creek serves to highlight a number of important issues, from regulation and education on pesticide use to stormwater system design. Bifenthrin had an extremely adverse impact on the aquatic macroinvertebrate community of the creek (including the population of *E. spinifer*), although recovery appears to be occurring relatively quickly.

Factors believed to assist recovery include the presence of good-condition, pesticide-unaffected tributary streams, allowing for rapid re-recruitment of animals into the main trunk of Jamison Creek. Inputs to the creek and its tributaries of high quality groundwater (via Blue Mountains Swamps) are also thought to have offset ongoing urban impacts and facilitated the re-establishment of a 'healthy' assemblage of aquatic biodiversity.

As well as having implications for the pest control industry and its regulators, the incident demonstrates the dangers of having urban areas directly connected to natural waterways via conventional stormwater infrastructure and highlights the importance of best practice water sensitive urban design, stormwater management, planning controls and education as protection for waterways. The presence of Bifenthrin in an upstream sediment sample suggests a separate contamination incident and highlights the need for further research into the frequency and nature of such pollution events.

Acknowledgments

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