SNOWY RIVER RECOVERY

SNOWY FLOW RESPONSE MONITORING

IMPACT OF THE 2002-03 WILDFIRES ON THE MACROINVERTEBRATE ASSEMBLAGES OF THE SNOWY RIVER CATCHMENT

SEPTEMBER 2008

NSW Government
Department of Water & Energy

Publisher

NSW Department of Water and Energy
Level 17, 227 Elizabeth Street
GPO Box 3889
Sydney NSW 2001

T 02 8281 7777 **F** 02 8281 7799

information@dwe.nsw.gov.au

www.dwe.nsw.gov.au

Snowy River Recovery
Snowy Flow Response Monitoring:
Impact of the 2002-03 wildfires on the macroinvertebrate assemblages of the Snowy River catchment

September 2008

ISBN 978 0 7347 5378 6

ISSN 1449 8022

Acknowledgements

Written by Matthew Russell. Co authored by Andrew Brooks and Simon Williams

Robyn Bevitt, Adam Boey, Bruce Cooper, Ivor Growns, Sam Lake, and Teresa Rose reviewed this report.

This publication may be cited as:

Russell, M., Brooks, A. and Williams, S. (2008) *Impact of the 2002-03 wildfires on the macroinvertebrate assemblages of the Snowy River catchment.* Snowy River Recovery: Snowy Flow Response Monitoring. Department of Water and Energy, Sydney

DWE 08_200

Contents

Figures

Tables

Abstract

Between December 2002 and March 2003 a wildfire burnt 4,142 km^2 of the Snowy River catchment including most of the Flow Response Monitoring and Modelling study sites. The percentage of upstream catchment area burnt above the study sites ranged from 3.34 to 73.5%. The wildfire left parts of the landscape susceptible to erosion. The wildfire was followed by a high flow event (HFE) of 965.8 Mld^{-1} recorded at Dalgety weir (downstream of Jindabyne Dam) on the 7 March 2003, which resulted in the transport and deposition of ash and sediment into river system.

The study team were concerned that the wildfire and HFE may mask the signal of the environmental flow releases, and decided to analyse the existing data to:

- determine if there were significant changes to abundance, family richness, and macroinvertebrate assemblage of both pools and riffles associated with the combined effects of the fire and HFE;
- assess evidence for recovery of affected sites; and,
- discuss the implications fire and HFE disturbance have had on the aquatic macroinvertebrate component sampled in the Snowy River flow response monitoring.

The upper Snowy River sites recorded the highest flows from the March 2003 HFE which attenuated downstream. The Snowy River at Dalgety received a mean daily discharge of 965 Mld^{-1} with a maximum instantaneous discharge of 9,239 Mld^{-1}. The magnitude of this short duration event discharge is capable of transporting some fine grain sediment in the Snowy River. The Mowamba River and Thredbo River showed smaller increases in river discharge at this time, indicating a localised rainfall event.

No significant linear relationship could be established between the “area of catchment burnt” and the macroinvertebrate fauna metrics for either pool or riffle habitats.

The fauna of the riffle meso-habitats were not affected by the wildfire. Running water habitats such as riffles, are not as susceptible to sediment/ash deposition as standing water habitats such as pools.

The fauna of some pools in the Snowy River showed signs of disturbance. The fauna of the Snowy River upstream of Sugarloaf Creek (Site 2) and the Snowy River at Mckillops Bridge (Site 7) were most affected, suffering a reduction in family richness and change in macroinvertebrate assemblages in the first post-fire year. The samples for these sites also showed signs of recovery within two years, however other studies on the impact of wildfire on aquatic macroinvertebrates suggest that there can be continued long-term effects post-fire. The difference between this study and the results of other studies possibly reflects the localised impact of the wildfire on the Snowy River study sites.

It is expected that the combined effect of wildfire and HFE will not mask any changes caused by flow releases as the most affected sites recovered in a relatively short period of time. Within two years the condition of the macroinvertebrate assemblages returned to within the variation of pre-fire conditions.

1. Introduction

The Snowy River Flow Response Monitoring and Modelling project attempts to measure the ecological responses to environmental water releases to the Snowy River. The project is a long-term interdisciplinary study that assesses the river attributes of hydrology, water quality, geomorphology, vegetation, macroinvertebrates and fish.

Between December 2002 and March 2003 a wildfire burnt through south-east New South Wales and north-east Victoria, the largest in the area since the 1939 Black Friday Fires. The wildfire burnt through 387,370 hectares of the Alpine National Park including the Snowy River catchment proper, and the sub-catchments of the Mowamba and Thredbo rivers (Rose and Henderson unpublished). The wildfire was also followed by a post Snowy Mountains Scheme high flow event (HFE) in March 2003, generally affecting the Snowy River below Jindabyne Dam.

The direct effects of wildfire can have negligible impact on stream insects, however, the aquatic macroinvertebrate fauna can be severely affected by post-fire flooding (Rinne 1996; Minshall *et al.* 1997; Minshall *et al*.2001a; Vieira *et al.* 2004). Vegetation loss and increased runoff, associated with burnt catchments, can cause severe physical alterations to stream morphology through increase erosion, scouring and sedimentation (Shakesby and Doerr 2006). This in turn affects macroinvertebrate density, and composition (Minshall *et al.* 2001b).

Ash flows associated with post wildfire runoff can also cause physiochemical changes to water quality and affect food quality in post-fire food-webs (Spencer *et al*. 2003). Changes to water quality can be dramatic but are usually short term and have been associated with decreases in macroinvertebrate densities in pool and riffle habitats (Earl and Blin 2003).

The reduction of riparian vegetation from fire reduces canopy shading of streams and can lead to elevated water temperatures which have been linked to significant decreases in macroinvertebrate density and richness (Minshall *et al.* 2001c). However, Minshall *et al.* (2001c) suggested that macroinvertebrate communities are more susceptible to physical alterations such as scouring and sedimentation rather than physiochemical or thermal changes within streams.

Field observations of the condition of the Snowy River monitoring sites after the wildfire and HFE indicated significant sediment deposition, particularly in the pool habitats. Running water habitats such as riffles appeared to be physically unchanged. It is estimated that sediment yield after the January – March 2003 fires were almost six times greater than what would have occurred in an unburnt Snowy River catchment (Cull 2005). In light of observed sedimentation processes, it was expected that the pools were more affected by the disturbance of fire and HFE than riffles resulting in a decrease in family richness and abundance leading to significant changes to macroinvertebrate assemblage composition. This change to macroinvertebrate communities has been documented in a number of studies regarding the effects of fire on macroinvertebrates (Rinne 1996; Minshall *et al.* 1995; Minshall *et al.* 2001a; Minshall *et al.* 2001b; Minshall *et al.* 2001c; Vieira *et al.* 2004). It is expected that this trend would be most prominent immediately after the fire and March 2003 HFE as the majority of sedimentation and erosion exacerbated by high flow events in burnt catchments occurs predominantly in the first year after fire (Robichaud 2000).

This study assesses the combined effect of a wildfire and a subsequent high flow event on macroinvertebrate abundance, family richness and assemblage composition.

The objectives of this report are:

- To determine if there were significant changes to abundance, family richness, and macroinvertebrate assemblage composition of both pools and riffles due to the combined effects of fire and the HFE,
- To detect if there is indication of recovery of macroinvertebrates at affected sites; and,
- To discuss the implications that fire and HFE disturbance on the aquatic macroinvertebrate component of the Snowy River flow response monitoring.

2. Study Area

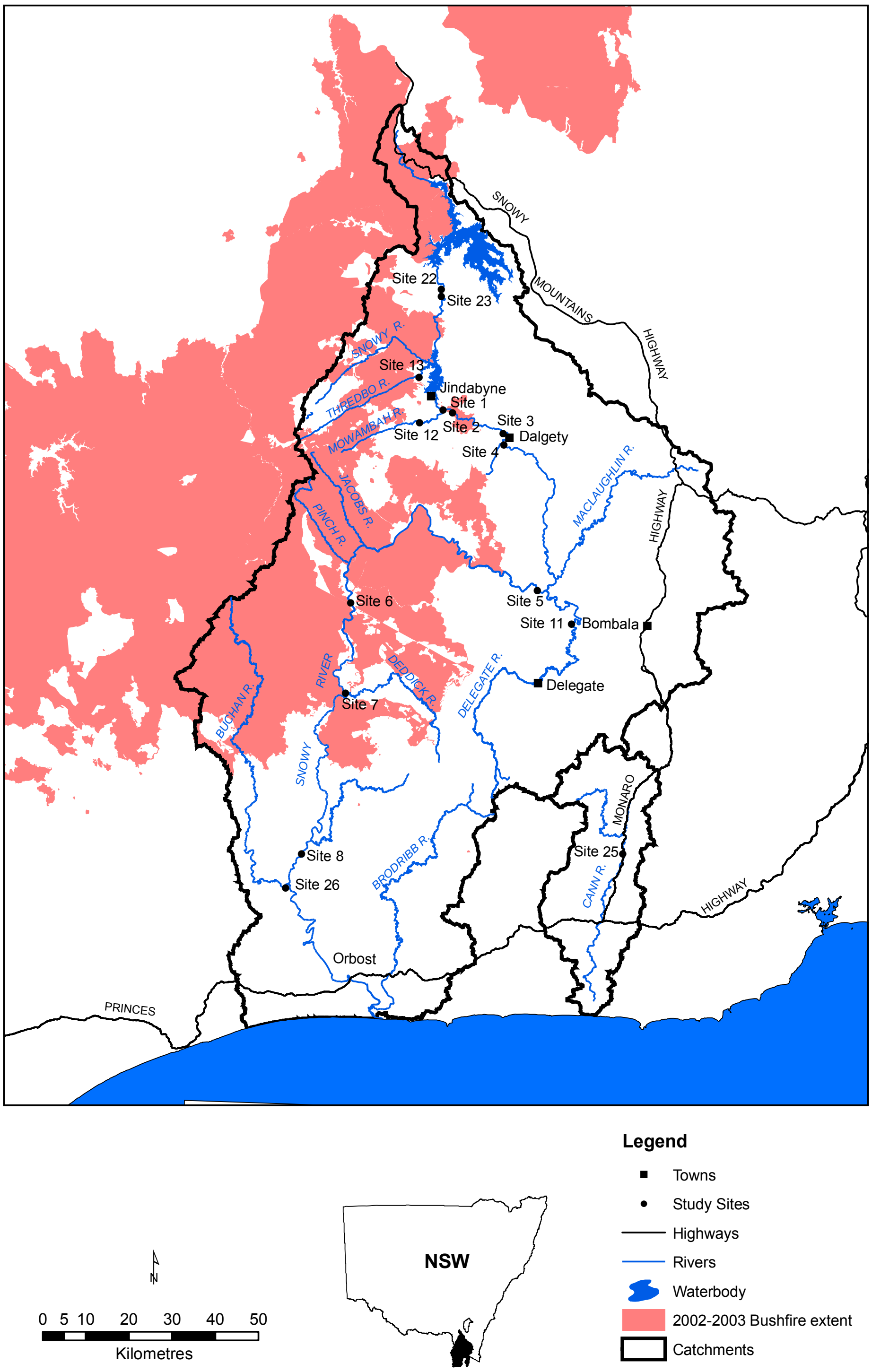
The Snowy River rises in the Australian Alps and has a catchment area of approximately 24,900 km^2. The Snowy River has two major dams in the upper catchment (ie. Jindabyne and Eucumbene), and downstream of Jindabyne Dam the river flows for 352 kilometres until it reaches the Tasman Sea near Orbost (Figure 1).

The sites used in this study are a subset of the Snowy River flow response monitoring study sites (Brooks *et al.* 2007) observed to be affected by the 2002-2003 wildfire and subsequent HFE. These sites include:

- Snowy River downstream of Mowamba River (Site 1),
- Snowy River upstream of Sugarloaf Creek (Site 2),
- Snowy River at Rockwell (Site 3),
- Snowy River downstream of Blackburn Creek (Site 4),
- Mowamba at Barry way (Site 12),
- Thredbo River at Pats Patch (Site 13),
- Snowy River at Willis (Site 6), and,
- Snowy River at Mckillops Bridge (Site 7);

The existing reference streams could not be used as reference in this analysis as all upland streams had at least part of their catchment burnt by fire (Figure 1). However, the lowland reference stream the Cann River (Site 25) was unburnt.

Figure 1. Location of study sites and area burnt by the 2003 wildfires in the Snowy River Catchment.



3. Methods

3.1 HYDROLOGY

The mean daily flows were graphed for the period January 2000 to 31st December 2005 from the data retrieved from Dalgety weir gauge 222026 (upstream Snowy gauge) and McKillops Bridge gauge 222209 (downstream Snowy River gauge), Thredbo River gauge 222541 and Mowamba River gauge 222546. The maximum instantaneous flows for the identified flow period were recorded where possible. Rainfall data were obtained from the Bureau of Meteorology.

The flood frequency analysis was undertaken using the River Analysis Package. Modelled and observed data for the period 1st January 1967 and 31st December 2005, were used to represent the post SMS period.

3.2 AREA OF CATCHMENT BURNT

The extent of the wildfire was quantified by determining the percentage of catchment area burnt upstream of each site. The catchments were derived from 25m cell size digital elevation models of NSW and Victoria in ARC view 3.3. The catchment area burnt was then calculated from existing digital wildfire layers (Department of Environment and Conservation unpub.). Simple linear regression analysis was used to examine the relationship of percentage of catchment area burnt to differences in autumn pre and post-fire mean total abundance, mean family richness, and mean similarity. The pre-fire data was compared to the autumn 2003 sampling season immediately post-fire period as changes to the macroinvertebrate assemblages were expected to be more distinguishable at this time. This was performed for both pools and riffle samples. A further description of direct impact of the fire was provided from Rose and Henderson (unpub.).

3.3 MACROINVERTEBRATES

3.3.1 Field Sampling Methods

Macroinvertebrate sampling commenced in 2000 and samples were collected in autumn and spring each year to date. Macroinvertebrates were sampled from three random points in each of two riffles and two pool edges at each site (total number of subsamples for each habitat= 6). Pool edge samples were collected from depths ranging 0.2m-0.5m within 2m of the bank. A suction sampler described by Brooks (1994) was placed over the substrate and operated for one minute at each sampling location. The sample was washed thoroughly over a 2mm mesh sieve nested above a 500µm mesh sieve. Matter retained on the 2mm sieve was placed in a large white tray and all invertebrates present were picked out on site into a jar of 70% ethanol. A second field officer checked all trays to ensure all invertebrates were removed. Material retained on the 500µm mesh sieve was preserved in 70% ethanol for laboratory sorting (Brooks *et al.* 2007).

3.3.2 Laboratory Procedures

Material retained on the 500µm mesh sieve in the field was stained with Rose Bengal and macroinvertebrates were picked under magnifying lamps. All macroinvertebrates (except for segmented and unsegmented worms) from both the coarse and fine fractions were identified to family level using dissecting and compound microscopes and published keys and descriptions (Hawking 2000). The segmented worms were identified to class (Oligochaeta). The unsegmented worms were identified to phylum, except for flatworms which were identified to order (Tricladida), and gordian worms which were identified to Family (Gordiidae). All macroinvertebrates were stored for possible future identification to lower taxonomic levels. For the individual taxa with extremely high abundance (>1000 estimated during sorting) retained in the 500µm mesh sieve fraction, 25% sub-sampling of the organism was undertaken using the subsampling box described by Marchant (1989). Typically, these taxa were Oligochaeta, Chironomidae, and/or Caenidae (Brooks *et al.* 2007).

3.3.3 Data Analysis

The analysis for this study uses data collected from autumn and spring seasons from 2000 to 2005, giving six sampling seasons before the fire/HFE and six sampling seasons post-fire/HFE. Each site was analysed separately due to the lack of suitable unburnt regulated reference streams for comparison.

The total abundance and family richness were calculated for each sample and the abundance data $\log_{10}$ transformed. Mean plots were produced for abundance and richness data for each site through time.

A general linear model ANOVA was applied to test whether there were differences between pre- and post-fire mean abundance ($\log_{10}$) and mean number of families. Six planned comparisons were conducted for abundance and for family richness of each site for both pools and riffles. The spring and autumn data were compared separately to limit the variability between spring and autumn samples that may otherwise mask significant change to abundance and richness taxa. The planned comparisons are listed in Table 1. A p level of 0.01 was considered significant. This level was used to limit the possibility of Type 1 error because of the number of comparisons. This analysis is used to test whether there is significant difference between pre-fire and post-fire univariate data, particularly within the first post-fire year when we expect most changes to occur, and to determine whether there is an indication of abundance and family richness recovery.

Table 1. Planned comparisons to assess the impacts of wildfire

Planned Comparisons
Mean autumn 2000-2002 (pre-fire) vs. autumn 2003 (post-fire)
Mean autumn 2000-2002 (pre-fire) vs. autumn 2004 (post-fire)
Mean autumn 2000-2002 (pre-fire) vs. autumn 2005 (post-fire)
Mean spring 2000-2002 (pre-fire) vs. spring 2003 (post-fire)
Mean spring 2000-2002 (pre-fire) vs. spring 2004 (post-fire)
Mean spring 2000-2002 (pre-fire) vs. spring 2005 (post-fire)

The abundance data of each taxonomic group were averaged for all six pool and for all six riffle samples at each site. A similarity matrix was derived by using Bray-Curtis similarity measure with abundance data transformed by log(x+1) (Clarke 1993). A non-metric Multi-Dimensional Scaling (nMDS) ordination was performed for each site to track the macroinvertebrate community changes through time and possible impacts due to fire disturbance.

The mean similarity and 95% confidence limits of pre- and post-fire samples were graphically compared to the mean and range of similarities between pre-fire samples. The graph was used to interpret the scale of any observed changes in the nMDS ordination to determine whether these changes are meaningful in respect to the fire and HFE disturbance.

The contributions of each taxon to the overall dissimilarity between pre-fire and post-fire samples were quantified by the SIMPER routine (Clarke & Warwick 1994). This was applied to sites that were interpreted as being significantly affected by 2002-2003 wildfire only. This analysis was used to determine whether the densities of particular macroinvertebrate families were affected by the wildfire/HFE and identify trends.

4. Results

4.1 HYDROLOGY

The high rainfall event in March 2003 was highly localised. Dalgety (071005) received 64.2 ml between 8th-9th of March 2003, while other areas in the upper catchment received 14.2 ml at Jindabyne (071041), 12.8 ml at Jindabyne Dam (071009), 24.3ml Thredbo Village (071014), 28.2 ml at Bobundara (070004), and 15.1ml at Poupong (071014). In the lower catchment (Victoria) the rainfall for this period was similarly variable with falls ranging between 19.3ml at Black Mountain (084044), 36.1 at Tubbut (084039), 15.1 ml at Buchan P.O (084005), and 30.8ml at Orbost. The highest falls recorded at Dellicknora (084014) of 46ml.

The mean daily discharge for the Snowy River at Dalgety weir post-fire was 965.8 Mld^{-1} in March 2003 (Figure 2). The maximum instantaneous discharge recorded was 9,239 Mld^{-1} indicating the HFE was of short duration compared to its average daily discharge. The flow of this magnitude is substantial in relation to its post SMS hydrological regime. The event of this size occurs or is exceeded more than 2% of the time, and generally equates to a 0.5 year ARI (ie. 926 Mld^{-1}) for the Snowy River at Dalgety, post SMS, 1967-2005 (Figure 3). Naturally the 0.5 year ARI would have been 15,921 Mld^{-1}. In comparison to median natural discharge (2,383 Mld^{-1}) for the period 1967-2005, the observed event is small, but compared to the observed median discharge (41.9 Mld^{-1}), it is large.

The mean daily discharges of Thredbo River, Mowamba River and the downstream Snowy River gauge at Mckillops Bridge indicate that the increased flows post-fire were minor compared to the flow events that have occurred in the studied six year period (Figure 2). The mean daily discharge at Thredbo River gauge of 178 Mld^{-1} is equal to or exceeded 60% of the time. Thredbo River peak instantaneous discharge was 1,029.67 Mld^{-1} over the entire month of March. McKillops Bridge gauge recorded a mean daily discharge of 571 Mld^{-1} which is equal to or exceeded 65% of the time. The peak instantaneous discharge was of only 2,090 Mld^{-1} showing that the high flow event recorded at Dalgety gauge attenuated downstream. The mean daily discharge at Mowamba River of 40.77 Mld^{-1} is equal to or exceeded approximately 43% of the time.

It appears as though the HFE recorded at Dalgety weir gauge was derived from the Wullwye Creek tributary rather Mowamba River or upstream of the Snowy River itself. Wullwye Creek and the Snowy River confluence is approximately 2km above Dalgety gauge. The Wullwye Creek gauge (222007) recorded mean daily discharge of approximately 1,300 Mld^{-1} which occurs or is exceeded only <1% of the time. The peak instantaneous discharge was approximately 8,100 Mld^{-1}.

The hydrological results imply that Site 3 and 4 located below Dalgety gauge were mainly affected by this flow event, while the other wildfire study sites received only moderate flows and rainfall.

Figure 2. Daily discharge of (A) Thredbo and Mowamba River (B) Snowy River at Dalgety Weir and Snowy River at Mckillops Bridge from January 2000 to December 2005. The daily discharge has been graphed at a logarithmic scale.

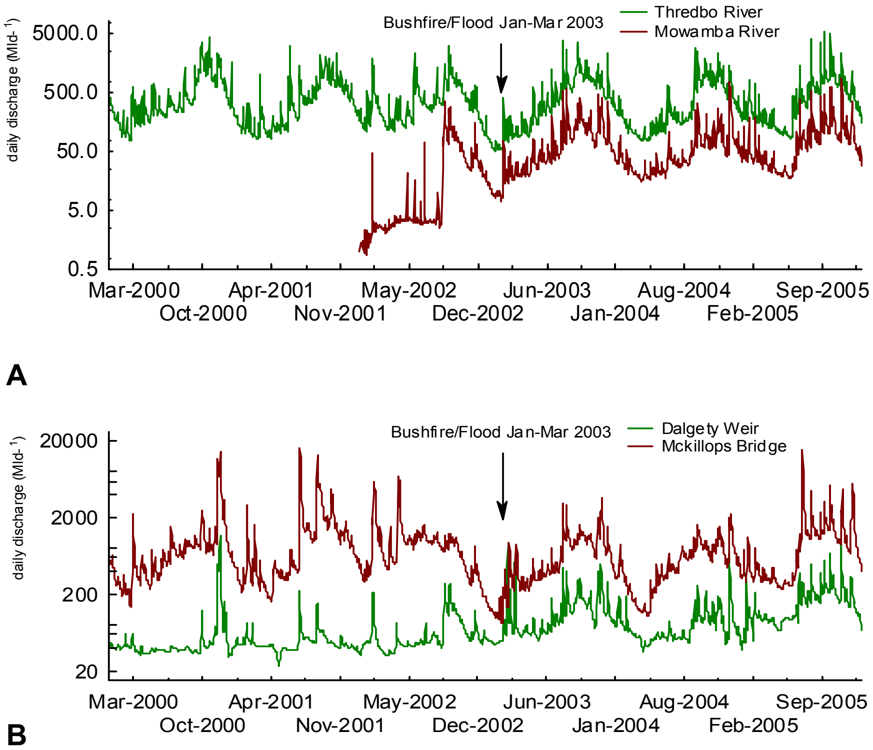
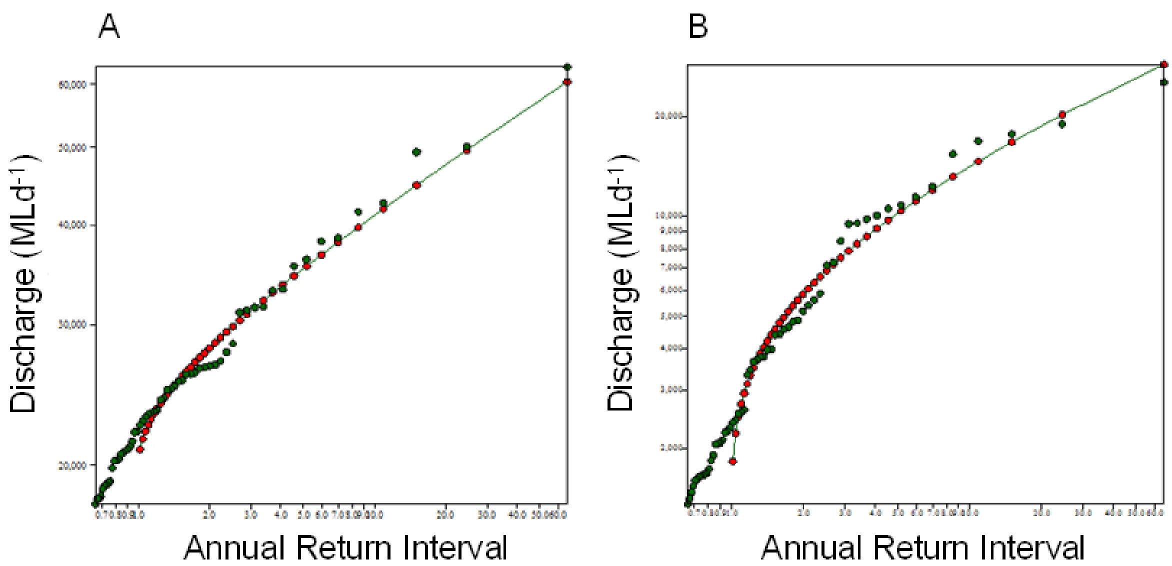


Figure 3. Flood frequency analysis (partial series) of the Snowy River at Dalgety using (A) modelled natural and, (B) observed discharge data, 1967-2005. The 1 year ARI for modelled natural is 20,838 Mld^{-1} and 1,813 Mld^{-1} for observed.



4.2 PERCENTAGE CATCHMENT BURNT

Descriptions of the direct wildfire impact and percentage catchment area burnt are provided in Table 2. It is apparent that a variety of fire regimes have directly affected the study sites. Similarly, the percentage area burnt is also variable ranging 3.34% to 73.5% across the study sites.

4.2.1 Pools edges

The regression analyses indicated that no significant linear relationship exists between catchment area burnt and the difference of mean autumn pre-fire and post-fire autumn 2003 sampling season for total abundance ($F_{1, 7}$=0.45, p>0.05); diversity ($F_{1, 7}$ =5.14, p>0.05); and similarity ($F_{1, 7}$ = 0.35, p>0.05) .

4.2.2 Riffles

Similarly the regression analyses for riffles indicated that no significant linear relationship exists between catchment area burnt and the difference of mean autumn pre-fire and post-fire autumn 2003 sampling seasons for total abundance ($F_{1, 7}$=4.376, p>0.05); diversity ($F_{1, 7}$ =0.386, p>0.05); and similarity ($F_{1, 7}$ = 0.097, p>0.05).

Table 2. Study sites, wildfire impact and percentage of catchment burnt.

Site	Direct wildfire impact	% of Catchment Burnt
Site 1 Snowy River downstream of Mowamba River (Hodges)	Left bank of the reach and the vegetated choke beyond cross section 8 was burnt by a low intensity fire	26%
Site 2 Snowy River u/s of Sugarloaf	Most of the reach was burnt by a hot fire	27%
Site 3 Snowy River at Rockwell	Not directly affected	16.75%
Site 4 Snowy River downstream of Blackburn Creek	Not directly affected	3.34%
Site 6 Snowy River at Willis	Low intensity burn above the Barry Way on the right bank	14%
Site 7 Snowy River at McKillops Bridge	Low intensity patch burn mostly on the left bank below the bridge	19%
Site 12 Mowamba River at the Barry Way	Not directly affected however the upper Mowamba River catchment has been extensively burned by fires of all intensities	36.5%
Site 13 Thredbo River at Paddys Corner	Most downstream cross section 9 and right bank to the gauge is burnt	73.5%
Site 25 Cann River	Not directly affected	0%

4.3 MACROINVERTEBRATES

The following macroinvertebrates results report the pool and riffle planned comparisons for each season of mean log_{10} abundance and mean family richness. The multivariate analysis will be discussed in relation to changes to Bray-Curtis similarity measure and SIMPER routine results are reported for sites for which this analysis was performed.

4.3.1 Pool edges

The univariate mean plots for abundance and family richness, nMDS ordination, control chart and planned comparisons are located in Appendix 1 Pool results.

Snowy River downstream of Mowamba River (Site 1)

The planned contrasts of total abundance for Site 1 indicated significant differences in almost all comparisons. Whilst the autumn comparisons show a decrease in abundance the spring comparisons indicate a significant increase in total abundance post-fire. The family richness comparisons show significant decrease in the first sampling season (autumn 2003) post-fire. The spring comparisons only indicated a statistical difference ($p<0.01$) between the spring pre-fire and last post-fire spring sampling season.

The multivariate analysis indicated that the average community similarities across sites between pre- and post-fire were within the range and close to the average of the pre-fire similarities. This implies that differences between post-and pre-fire samples are within the natural assemblage composition and temporal variation for this site.

Snowy River upstream Sugarloaf Creek (Site 2)

Site 2 showed no significant differences between any abundance comparisons. However, a significant decrease in family richness was detected immediately after the fire/HFE for both autumn and the following spring. These post-fire observations are well below the range of pre-fire observations. There also appears to be recovery of the fauna with family richness increasing to be near pre-fire levels, although there is significant decrease in average family richness again in spring 2005.

The nMDS ordination portrays a sharp change in assemblage composition in post-fire autumn 2003 samples. This result is emphasised particularly by the similarity mean plot as the first four post-fire sampling seasons similarities are beyond the range of pre-fire similarities. The results imply an extended impact caused by the wildfire/HFE disturbance.

The SIMPER analysis showed that taxonomic groups Caenidae, Tricladida, Gomphidae, in order of decreasing % contribution, contributed 20% of the overall dissimilarity (Table 3).

Table 3. Comparison of the pre and post-fire average abundance, average dissimilarity, dissimilarity/standard deviation, percent contribution and cumulative percentage contribution for fauna at the Snowy River upstream of Sugarloaf Creek (Site 2).

	Pre-fire	Post-fire				
Species	**Av. Abundance**	**Av. Abundance**	**Av. Dissimilarity**	**Diss/SD**	**Contribution%**	**Cum.%**
Caenidae	96.72	28.14	3.3	1.25	7.64	7.64
Tricladida	12.81	1.22	3.04	2.00	7.04	14.68
Gomphidae	16.17	4.58	2.58	1.54	5.98	20.66
Hydroptilidae	10.86	0.28	2.41	1.66	5.57	26.23
Ecnomidae	7.44	0.39	2.15	1.54	4.98	31.21
Chironomidae	60.28	55.19	2.01	1.9	4.65	35.86
Nematoda	2.64	12.06	2.00	1.94	4.64	40.5
Leptoceridae	4.50	8.11	1.93	2.17	4.46	44.95
Corixidae	0.14	10.36	1.88	1.04	4.34	49.30
Physidae	3.69	0.67	1.67	1.60	3.86	53.16

Snowy River at Rockwell (Site 3)

In Site 3, the planned contrasts show a significant increase (p <0.01) in abundance in autumn 2003 and a significant decrease in autumn 2005. The spring average log abundances were not significantly different between pre-fire and any individual post-fire season. The family richness comparisons indicated significantly lower diversity between autumn 2004, 2005 samples and the combined pre-fire autumn samples. Spring 2003, and spring 2004 samples were also significantly lower than the pre-fire spring samples. Spring 2003 observation in particular, was well below the minimum family richness of spring pre-fire observations.

The nMDS ordination indicated no change in macroinvertebrate assemblage composition immediately after the fire, although the average similarity decreases in spring 2003. The seasons, autumn 2004-spring 2005, have similarity between pre-and post -fire samples close to that of the similarity of pre- fire samples.

Snowy River downstream of Blackburn Creek (Site 4)

There were no significant differences between pre- and post-fire mean abundances for both seasons. No significant differences were also apparent in family richness between the first two post-fire samples and that of pre-fire autumn 2003 and spring-2003 samples. However, family richness of the autumn 2004, spring 2004 and spring 2005 were significantly lower than their corresponding pre-fire seasonal samples. These observations were also outside the range of pre-fire observations.

There was no significant change in macroinvertebrate community structure in the initial autumn and spring post-fire sample. The average similarity decreased considerably in spring 2005 falling outside the range of pre-fire similarities.

Snowy River at Willis (Site 6)

The log abundance contrasts for Site 6 indicate that there were no significant differences of any autumn post-fire samples compared to the pre-fire samples. The post-fire spring samples showed significant decreases from pre-fire averages for all occasions. The family richness contrasts showed significant decreases in autumn 2003 and spring 2003 post-fire samples, falling below the range of pre-fire observations.

The multivariate ordination and similarity mean plots portray a decrease in similarity particularly in the spring 2003 sample. There appears to be a less similar community composition in autumn 2003, however the mean lies within the range of pre-fire similarities. The univariate family richness and multivariate results may implicate disturbance by wildfire/HFE, therefore a SIMPER analysis was applied to the pre-fire samples and the first two post-fire sampling seasons.

SIMPER analysis of the log abundance data showed that a decrease in Heterodonta (Mollusca), Ecnomidae, Baetidae, and Gomphidae contributed to approximately 23% of the overall dissimilarity (Table 4).

Table 4. Comparison of the pre and post-fire average abundance, average dissimilarity, dissimilarity/standard deviation, percent contribution and cumulative percentage contribution for fauna at the Snowy River at Willis (Site 6).

	Pre-fire	Post-fire				
Species	**Av. Abundance**	**Av. Abundance**	**Av. Dissimilarity**	**Diss/SD**	**Contribution%**	**Cum.%**
Heterodonta	88.06	44.92	1.98	1.26	6.16	6.16
Ecnomidae	10.08	2.42	1.9	1.67	5.91	12.08
Baetidae	14.47	3.22	1.83	1.41	5.67	17.75
Gomphidae	35.11	9.11	1.75	1.32	5.43	23.18
Corixidae	0.58	8.33	1.52	1.38	4.71	27.89
Caenidae	574.11	151.72	1.45	1.54	4.52	32.41
Hydrophilidae	13.69	3.81	1.43	1.31	4.46	36.86
Leptoceridae	6.92	7.25	1.42	1.43	4.43	41.29
Leptophlebiidae	30.36	12.00	1.41	1.44	4.39	45.68
Hydroptilidae	4.94	5.47	1.32	1.41	4.12	49.80
Gripopterygidae	4.50	1.64	1.28	1.23	3.97	53.77

Snowy River at McKillops Bridge (Site 7)

There was a significant decrease in abundance in the first post-fire sampling season autumn 2003, falling below the range of pre-fire observations. The pre-fire spring samples showed no significant difference with the first spring post-fire sample, although differences are evident with the spring 2004 and spring 2005 samples. There were significant lower family diversities in the first four sampling seasons post-fire. In the first two post-fire sampling seasons the average family richness reduced by approximately 50%, well below the range of pre-fire observations.

The multivariate analysis portray change in assemblage composition in the similarities of the first two post-fire sampling seasons autumn 2003 and spring 2003. These are well below the average and range of pre-fire similarities.

A SIMPER analysis was performed on the first two post-fire seasons compared to all pre-fire samples to determine the taxonomic families responsible for the change in community structure (Table 5). The results of the SIMPER analysis showed that a decrease in Caenidae, Gomphidae, Heterodonta, Baetidae, were the highest contributors to the overall dissimilarity (35% contribution).

Table 5. Comparison of the pre and post-fire average abundance, average dissimilarity, dissimilarity/standard deviation, percent contribution and cumulative percentage contribution for fauna at the Snowy River at McKillops Bridge (Site 7).

	Pre-fire	Post-fire				
Species	**Av. Abundance**	**Av. Abundance**	**Av. Dissimilarity**	**Diss/SD**	**Contribution%**	**Cum.%**
Caenidae	235.86	8.67	6.17	3.1	11.49	11.49
Gomphidae	24.14	0.50	4.75	4.85	8.85	20.34
Heterodonta	44.44	2.67	3.99	1.84	7.44	27.78
Baetidae	19.56	0.17	3.79	1.57	7.06	34.84
Hydrophilidae	14.14	0.25	3.29	1.67	6.13	40.97
Oligiochaeta	48.94	128.5	2.71	1.50	5.05	46.02
Leptoceridae	3.86	0.00	2.15	1.53	4.01	50.04

Mowamba River (Site 12)

No significant difference in abundance was apparent between any pre-fire and post-fire comparisons for both seasons. The family richness shows a significant decrease in the first autumn post-fire and pre-fire comparison and there appears to be seasonal differences between spring and autumn samples with autumn consistently having a higher family richness.

The multivariate data implies that the first post-fire season is similar to the pre-fire sample similarities, however, the following season from spring 2003 to spring 2005 are outside the range of the pre-fire similarities. Although the first season portrayed no abrupt change in the multivariate data, a SIMPER analysis was performed between pre-fire and all post-fire samples to determine the changes to the macroinvertebrate assemblage composition.

The SIMPER results showed that a decrease in the mayfly families Leptophlebiidae and Baetidae and an increase in Oniscigastridae contributed to 20% of the overall dissimilarity (Table 6).

Table 6. Comparison of the pre and post-fire average abundance, average dissimilarity, dissimilarity/standard deviation, percent contribution and cumulative percentage contribution for fauna at the Mowamba River (Site 12).

	Pre-fire	Post-fire				
Species	**Av. Abundance**	**Av. Abundance**	**Av. Dissimilarity**	**Diss/SD**	**Contribution%**	**Cum.%**
Leptophlebiidae	14.50	0.42	3.31	3.65	8.47	8.47
Baetidae	19.25	3.5	2.47	2.04	6.32	14.79
Oniscigastridae	3.31	10.06	2.30	1.27	5.9	20.69
Heterodonta	37.64	33.97	2.29	1.82	5.87	26.57
Elmidae	21.36	16.06	1.92	1.43	4.92	31.49
Caenidae	14.06	4.97	1.75	1.48	4.49	35.98
Hydropsychidae	2.58	6.44	1.68	1.40	4.30	40.28
Nematoda	3.53	12.42	1.66	1.27	4.26	44.53
Gripopterygidae	4.39	2.39	1.53	1.18	3.91	48.44
Nemertea	0.08	2.89	1.40	1.30	3.58	52.02

Thredbo River (Site 13)

The log abundance planned comparison showed that there was a significant decrease in the first three post-fire seasons compared with the corresponding average pre-fire abundances. The abundance data decreased again sharply in spring 2005. The family richness contrasts indicated that there was a significant decrease between all autumn post-fire samples and pre-fire samples. Although the post-fire spring observations of family richness fell below the range of spring pre-fire observations, the reduction was only significant in spring 2005.

The nMDS ordination and similarity mean plot show a decrease in similarity in the first three post-fire seasons compared to the similarity of pre-fire similarities. In spring 2004 and autumn 2005 the average similarity between post-fire and pre-fire are within the range of pre-fire similarities. In spring 2005 the similarity drops markedly falling well below the range of pre-fire similarities.

The SIMPER routine was performed on the first three post-fire sampling seasons compared to all pre-fire samples (Table 7). The results indicated that Oniscigastridae, Gripopterygidae, Chironomidae, Heterodonta, Caenidae, contributed to 33% of the overall dissimilarity of the abundance data. The taxa Oniscigastridae, Gripopterygidae, Chironomidae, Caenidae showed a decrease in abundance, however there was an increase in the order Heterodonta, which at this site comprises only of the family Sphaeridae.

Table 7. Comparison of the pre and post-fire average abundance, average dissimilarity, dissimilarity/standard deviation, percentage contribution and cumulative percentage contribution for fauna at Thredbo River (Site 13).

Species	Pre-fire Av. Abundance	Post-fire Av. Abundance	Av. Dissimilarity	Diss/SD	Contribution%	Cum.%
Oniscigastridae	37.78	1.56	3.95	1.14	9.11	9.11
Gripopterygidae	8.69	1.00	2.89	2.28	6.67	15.79
Chironomidae	78.00	17.94	2.55	3.97	5.90	21.68
Heterodonta	3.86	11.33	2.53	2.29	5.84	27.52
Caenidae	15.81	4.94	2.49	1.43	5.76	33.28
Ceratopogonidae	28.00	8.89	2.07	2.46	4.79	38.07
Elmidae	5.14	0.50	1.96	1.25	4.52	42.59
Hydroptilidae	3.89	0.67	1.78	1.21	4.10	46.69
Baetidae	7.33	3.06	1.77	1.81	4.08	50.77

Cann River (Site 25)- unburnt

There was a significant abundance increase in the first autumn post-fire samples, but the average value was within the range of pre-fire autumn observations. Significant decrease in average abundance was apparent between pre-fire spring samples and spring 2005 post-fire sample. The family richness data indicated that there were no significant differences between any planned contrasts except for autumn 2005 sample and autumn pre-fire samples. However, this mean is within the range of pre-fire autumn observations.

There is no difference between pre and post-fire community assemblages as the average similarity of post-fire and pre-fire samples is close to the average and within range of the similarities of pre-fire samples.

4.3.2 Riffles

The univariate mean plots for abundance and family richness, nMDS ordination, control chart and planned comparisons are located in Appendix 2 Riffle results.

Snowy River downstream of Mowamba River (Site 1)

Macroinvertebrate mean log abundance show no significant difference immediately post-fire in autumn 2003, however there are significant decreases in autumn 2004 and 2005 which fall below the range of pre-fire observations. Mean family richness also show no significant difference in the autumn season immediately following the fire, however significant decrease was apparent the following year in autumn 2004.

The similarity mean plot shows that mean seasonal similarities post-fire were with in the range of mean pre-fire similarities.

Snowy River upstream Sugarloaf Creek (Site 2)

There was no significant difference between pre and post-fire comparisons in the 2003 sampling seasons post-fire. A significant decrease ($p<0.01$) was recorded for the mean pre-fire and autumn 2005 comparison. The mean family richness comparisons only showed significant decrease between the mean pre-fire spring samples and spring 2004 comparison.

The mean plot of similarity indicates that the post-fire autumn and spring similarities means were close to and within range of mean pre-fire similarities.

Snowy River at Rockwell (Site 3)

There were no significant differences detected for any of the mean abundance comparisons. Family richness results indicated a significant difference between means for both the spring and autumn pre-fire and post-fire 2004 comparison. These observations fell below the range of pre-fire observations.

The mean similarity of the first year post-fire is close to and within range of pre-fire similarities. In spring 2004, the mean similarity falls outside the range of pre-fire similarities.

Snowy River downstream of Blackburn Creek (Site 4)

In the autumn pre-fire verses the autumn 2003 post-fire comparison there was a significant increase in mean abundance. A significant decrease was recorded between the autumn pre- fire and autumn 2005 post-fire sampling season which is well below the range of pre-fire autumn observations. There was no significant difference ($P<0.01$) for any of the spring comparisons.

The mean family richness results show that there was no significant difference between pre-fire and the following 2003 autumn however there was a significant decrease in spring 2003. Significant decreases were also recorded for the spring and autumn 2005 sampling seasons verses the pre-fire data. All observations post-fire were below the range of any pre-fire observations.

The nMDS ordination and the Bray Curtis similarity measure mean plot indicates that the first two post-fire mean similarities was close to and within range of pre-fire similarities however became less similar in spring and autumn 2005.

Snowy River at Willis (Site 6)

Significant increases in mean abundance were recorded for all autumn comparisons however no significant differences were recorded for any of the spring comparisons even though they were above the range of pre-fire observations. Mean family richness data only showed significant increase between spring 2004 post-fire verses spring pre-fire comparison. The mean abundance and mean family richness appear to show seasonal fluctuations with autumn having higher mean abundance and family richness compared to spring samples.

The Bray Curtis similarity mean plot indicates that the mean similarity for post-fire seasons were all close to the mean and with in range of pre-fire similarities.

Snowy River at Mckillops Bridge (Site 7)

No significant differences were recorded for mean abundance between the first post-fire year and their corresponding pre-fire comparisons. Significant decreases were evident in autumn 2004 and 2005 and their pre-fire autumn comparisons. These observations were with range of pre-fire autumn observations. There was significant increase in mean abundance in spring 2005. Mean family richness results show significant decreases for all autumn comparisons whereas no significant differences were recorded between any of the spring comparisons.

The Bray Curtis similarity mean plot indicates that post-fire similarities were close to the mean and with in range of pre-fire similarities.

Mowamba River (Site 12)

A significant difference in mean log abundance was only recorded between spring 2005 post-fire and the spring pre-fire comparison. The mean family richness shows significant decreases in post-fire autumn 2004 and 2005 and the pre-fire autumn comparisons which also fell below the range of pre-fire autumn observations. A significant decrease was evident between the post-fire spring 2005 and the spring pre-fire comparison. All spring post-fire observations were below the spring pre-fire range. The mean abundance and mean family richness appear to show seasonal fluctuations with autumn having higher mean abundance and family richness compared to spring samples.

The Bray Curtis similarity mean plot indicates that most post-fire similarities were close to the mean and with in range of pre-fire similarities. Spring 2005 shows a decrease in similarity compared to the mean pre-fire similarities.

Thredbo River (Site 13)

A significant decrease in mean log abundance was only recorded in the autumn 2005 post-fire verses autumn pre-fire comparison. This observation was with in range of pre-fire observations. This was also reflected in the mean family richness which showed significant decrease in the same seasonal comparison and yet fell within the range of pre-fire observations. The mean abundance and mean family richness both appear to portray seasonal fluctuations between spring and autumn. The autumn seasons appear to have higher mean abundance and mean family richness than the spring sampling seasons.

The Bray Curtis similarity mean plot indicates that the post-fire similarities were close to the mean and within range of pre-fire similarities.

Cann River (Site 25) -unburnt

There were significant increases apparent in mean abundance between autumn 2003, autumn 2005 and their pre-fire autumn comparison. No significant differences were evident in any of the mean family richness comparisons. The post-fire autumn 2003 and 2005 observations for both abundance and family richness fell above the range of pre-fire autumn observations.

The Bray Curtis similarity mean plot shows that post-fire similarities were close to and with in range of pre-fire similarities.

5. Discussion

5.1 EFFECT OF WILDFIRE AND HFE ON MACROINVERTEBRATE FAUNA

Post wildfire, the Snowy River at Dalgety received a mean daily discharge of 965 Mld^{-1} with a maximum instantaneous discharge of 9,239 Mld^{-1}. Post the SMS, and event of this size generally equates to a 0.5 year ARI (ie. 926 Mld^{-1}) for the Snowy River at Dalgety. Naturally the 0.5 year ARI would have been 15,921 Mld^{-1}. Although large for the post SMS, the observed event is less than the median natural discharge (2,383 Mld^{-1}) for the period 1967-2005.

Hydraulic modelling by Reinfelds and Williams (in prep) indicate that discharge events of 1,000 Mld^{-1} are capable of transporting and depositing fine grain sediment in the Snowy River. Field observations of the combined effect of wildfire and the HFE support the hydraulic modelling results. The river channel in the Jindabyne Gorge became choked with deposits of hill slope debris and sediment. Sedimentation of pool habitats by ash and fine silt was common, but the riffle habitats generally appeared to have unchanged geomorphology (Russell, personal observation). The sites further downstream of the Snowy-Delegate River confluence showed some minor sediment deposition and erosion of the substrate (Rose, in prep.). Typically, these differences in physical site changes appear to reflect the localised differences in the (i) area burnt, (ii) rainfall, and (iii) differential responses by running and standing water habitats.

The physical disturbance of wildfire and HFEs such as channel alteration, sediment transport and deposition have been found to cause greater impact to aquatic fauna rather than chemical or thermal changes (Minshall *et al.* 2001a, 2003). Short term changes to macroinvertebrates have been associated with poor water quality from the input of ash into streams (Earl and Blinn 2003; Rinne 1996, Bowman and Bloggs 2006, Spencer *et al*. 2003). However, the impacts of chemical changes have been considered less significant compared with longer term physical impacts to stream morphology and aquatic habitat (Minshall 2003).

The functioning of stream processes can change in response to fire disturbance. The changes to stream processes such as sediment transport, erosion and deposition can be attributed to physical disturbance from substantial hydrological events and the increase in sediment load and erosion in the first few years following wildfire (Minshall *et al.* 1997, 2001a). Fire can also increase the sensitivity of the burnt streams to local scale disturbances of heavy localised precipitation (Minshall *et al* 2001a, Shakesby and Dorre 2006). This could partly account for the difference in responses to disturbance between sites particularly since they are spatially distant, and had substantially differing daily discharges at the time of the March 2003 HFE event.

The size of the stream and extent of catchment burnt has been shown to influence the effects on aquatic macroinvertebrates (Minshall 2003). Minshall (2003) concluded that smaller streams where more susceptible to fire impacts than larger streams. Additionally, Minshall (2003) identified a larger disturbance to macroinvertebrate assemblages in catchments with a greater proportion of their catchment area burnt. In the Snowy catchment, however, a non-significant relationship between impact on macroinvertebrates and percentage of catchment area burnt was observed with this study. This non significant result possibly reflects the limited number of sites used in the study, to establish the relationship. The lack of suitable unburnt reference streams available for upland sites for this study made it difficult to determine whether patterns of the disturbed macroinvertebrate assemblages are the result of the wildfire and the HFE or a result of other abiotic and biotic factors such as competition or drought. Hence the study relies primarily on observed relative changes to macroinvertebrate assemblage composition through time with no comparative reference to account for the other environmental factors.

The fauna in riffle environments showed no clear response to the wildfire/HFE, but some pool edge biota did exhibit more obvious responses to the disturbance. These pool edge responses include decreases in abundance, family richness and changes to the community assemblage. These responses are individualistic in nature and appear to be the result of local scale impacts to run off and stream processes, particularly sedimentation in pool environments as this was a common process observed in these pool habitats and absent from riffle habitats. The changes to pool macroinvertebrates in burnt catchments appeared to be caused by moderate rainfall and flow events.

5.1.1 Riffle fauna

The results of this study indicate no clear fire impact on riffle macroinvertebrate richness, abundance or assemblage structure at the studied sites in the Snowy River catchment. However, previous studies have shown that fire and hydrological disturbances in streams caused significant changes to abundance, richness and assemblage structure fauna in lotic habitats (Vieira *et al.* 2004;). Declines in family richness are often associated with wildfire impact, however, overall macroinvertebrate abundance does not always decrease after a wildfire (Vieira *et al.* 2004; Minshall *et al.* 2001b). The decrease in abundance in individual families can be masked by an increase in other families that favour disturbed environments (Vieira *et al.* 2004; Minshall *et al.* 2001b).

The difference in results between the present study and other studies of wildfire/HFE impact on riffle fauna may be attributed to the differing hydrological regimes, stream processes and geomorphic characteristics between studied streams and their catchments. The limited physical disturbance to the riffle habitat could also account for the lack of obvious change to abundance, richness and assemblage composition. Another possible reason for the lack of disturbance observed in riffle fauna is that the impact was of a short duration and the riffle fauna had recovered prior to the autumn 2003 sampling.

5.1.2 Pool edge fauna

The pool edge fauna at the Snowy River upstream of Sugarloaf Creek (Site 2) and Snowy River at McKillops Bridge (Site 7) were significantly impaired. The pool edge fauna at Snowy River at Willis (Site 6), Mowamba River (Site 12), and the Thredbo River (Site 13) were less affected. The pool fauna of the upper Snowy River sites 1, 3, and 4, appeared to be unaffected by the combined disturbance of wildfire and HFE. These results for the pool edge fauna indicate a localised response to the wildfire.

The wildfire impacts on pool edge fauna include significant decreases in abundance and family richness and less similar assemblage structure. The mechanisms for these changes in fauna are less clear. Changes to water quality have been shown to cause significant reduction in macroinvertebrate abundance and richness post-fire (Earl and Blinn 2003; Rinne 1996) and shifts in plant food resources have been shown to affect assemblage structure (Minshall 2001c, Spencer *et al*. 2003). However physical factors such as turbidity, sedimentation and scouring appear to have an overriding influence on macroinvertebrate assemblage structure (Minshall 2003).

It appears there is not one family commonly affected by the wildfire. Studies have shown that some opportunistic species of mayflies (Baetidae), dipterans (Chironomidae), and stoneflies increase in abundance after fire (Minshall *et al.* 2001b). While this was apparent in some affected sites for the mayfly family Oniscigastridae, the trend was not consistently observed. There was an increase in nematodes and oligochaetes, but this again was not observed at all impacted sites. The general trend at affected sites was a reduction in densities across most families. The family Caenidae decreased in abundance in all affected sites, however this was also observed in unaffected sites. This change is unlikely to be exclusively caused by the wildfire as macroinvertebrate assemblages of the pool edge habitats within the midland and lowland macro-reaches of the Snowy River exhibited drought related effects (Brooks *et al.* 2007). The suggested drought effects include a decline in densities of most macroinvertebrate families and increased densities of oligochaete worms (Brooks *et al.* 2007).

The fauna at the Snowy River (Site 6), Mowamba River (Site 12) and the Thredbo River (Site 13) did show a response to the wildfire, but to a lesser extent than the Snowy River upstream of Sugarloaf Creek (Site 2) and the Snowy River at McKillops Bridge (Site 7). These macroinvertebrate assemblages at these sites were similar (within the range of pre-fire Bray Curtis similarity) to macroinvertebrate assemblages sampled immediately post-fire. The macroinvertebrate fauna showed substantial decreases in assemblage similarity in the second sampling occasion post-fire. This may correspond to the increased flow regime in the spring months and the increase in sedimentation and erosion processes.

The macroinvertebrate samples at the Snowy River downstream of the Mowamba River (Site 1) did not appear to be affected by the low intensity fire in this area. This is consistent with studies on the effects of prescribed fire on a Sierra Nevada stream and its riparian zone which showed that little to no response was observed in the macroinvertebrate abundance, richness or diversity despite a rainfall event following a low intensity burn (Bêche *et al.* 2005).

The macroinvertebrate samples at the Snowy River at Rockwell (Site 3) and downstream of Blackburn Creek (Site 4) were similarly not affected by the fire and HFE. The aquatic macroinvertebrates remained unaffected even though these sites where located in close proximity to the gauges which recorded the highest rainfall and flows. At these sites only a comparatively low catchment area was burnt and there was no fire in the immediate area. These sites are well downstream of the area of catchment burnt and any disturbance caused by fire would be likely to be smaller and therefore more difficult to detect.

5.2 FAUNA RECOVERY

This study comprises of six sampling seasons in three years after the wildfire, and there appears to be an indication of recovery for the sites greatly impacted by the wildfires (Sites 2 and Site 7). The macroinvertebrate family richness and assemblage post-fire data became more similar to pre-fire data within two years. In Victoria, studies on the Caledonia wildfire in 1997/88 have also shown possible recovery of macroinvertebrate richness and macroinvertebrate assemblage composition one year after fire (Papas *et al.* unpub.).

Other studies have indicated that fire-related disturbance may influence stream function for up to ten years as a result of physical disturbance from enhanced peak discharges and increase sediment input in the first few years post-fire (Robinson *et al* 2005). Macroinvertebrates in Cache Creek after Yellowstone National Park wildfire in the U.S.A. have also taken as long as 10 years to recover to pre-fire conditions (Minshall *et al.* 2001b). Studies on post-fire central Idaho streams have reported community level effects of fire on macroinvertebrate measures such as richness and abundance have dissipated with in seven years (Minshall *et al.* 2001c). There has also been evidence that macroinvertebrate abundance in burnt canyon streams that are susceptible to flash flooding, recovered in two years due to rapid colonisation of opportunistic species, however taxon richness was less resilient and only recovered in four years. The community composition in the canyon streams still had not recovered in six years after wildfire (Vieira *et al.* 2004). These international studies highlight the potential long-term impacts of wildfire can have on aquatic fauna. The Snowy River, Mowamba River and Thredbo River may yet exhibit these long-term effects such as an increase in variability within sites as a result of increased susceptibility to local runoff and sedimentation processes. Each site is unique and has differing direct and indirect effects of fire, hydrological regime and stream characteristics resulting in individual responses to disturbance and its recovery (Minshall *et al* 2001c).

5.3 IMPLICATIONS FOR THE SNOWY RIVER FLOW RESPONSE MONITORING

The analysis of the macroinvertebrate component of the Snowy River Flow Response Monitoring relies on the comparison of Snowy River sites to reference and control sites. The study is unlikely to be confounded by the impact of wildfire and HFE as the affected sites appear to have exhibited a relatively quick recovery or no disturbance at all. The fauna at the most affected sites, the Snowy River upstream of Sugarloaf Creek (site 2) and at Mckillops Bridge (site 7) particularly show this marked recovery. It is expected that the type and magnitude of macroinvertebrate change caused by environmental flows will not be masked by the effects of wildfire and HFE.

In future, it is recommended that the data from the most fire affected sites (sites 2 and 7) be reassessed to fully assess the long-term recovery of macroinvertebrate assemblages to fire impacts. Minshall (1995) suggests that one effect of the fire was to alter the substrata to make the benthic habitat more vulnerable to future disturbances. The annual variations with macroinvertebrate communities tend to become more attenuated in time (7-10) years, however they may show greater within year variability for a unknown number of years (≥15 years) (Minshall *et al.* 2001a,b, 2003).

6. References

Bêche L. A, Stephens S. L., and Resh V H. (2005) Effects of prescribed fire on a Sierra Nevada (California, USA) stream and its riparian zone *Forest Ecology and Management* 218: 37-50.

Bowman D.M.J.S and Bloggs G.S (2006) Fire Ecology *Progress in Physical Geography* 30 pp. 245-257

Brooks A., Bevitt. R, Dasey M, and Russell. M, (unpub) Macroinvertebrate Assemblages of the Snowy River, Report of sampling spring 1999-autumn 2000, Department of Natural Resources

Brooks A, Bevitt. R, and Russell. M (June 2007) Response of aquatic macroinvertebrates to the first environmental flow regime in the Snowy River. New South Wales Department of Water and Energy.

Brooks S. (1995). An efficient and quantitative aquatic benthos sampler for use in diverse habitats with variable flow regimes. *Hydrobiologia* 281, 123-128.

Chessman B.C. (1986) Impact of the 1983 wildfires on river water quality in East Gippsland, Victoria *Australian Journal of Marine and Freshwater Research* 37 : 399-420.

Clarke K.R (1993) Non–Parametric multivariate analyses of changes in community structure *Australian Journal of Ecology*. 18: 117-143

Crowther D. and Papas P. (2005) Determining the impact of fire on invertebrate communities in alpine streams in north-east Victoria. Report to DSE, Melbourne Freshwater Ecology, Arthur Rylah institute for Environmental Research, Technical Report Series No.156, Department of Sustainability and Environment, Melbourne.

Cull J (2005) Investigation of the quantity of sediment deposited into the Snowy River following the January – March 2003 bushfires. Report to the Snowy Mountains Bushfire Recovery Taskforce, NSW Premiers Department, Queanbeyan, Australia.

Earl S. R. and Blinn W. (2003) Effects of wildfire ash on water chemistry and biota in South-Western U.S.A. stream *Freshwater Biology* 48 : 1015-1030.

Marchant R**.** (1989). A subsampler for samples of benthic invertebrates *Bulletin of the Australian Society for Limnology* 12, 49–52.

Minshall W.G., Royer T.V., Robinson C.T and Rushforth S.R. (1995) Benthic community structure in two adjacent streams in Yellowstone National Park five years after the 1988 wildfires *The Great Basin Naturalist* 55 : 193-200.

Minshall W.G., Brock J.T., Andrews, D.A. and Robinson C.T., (2001a) Water quality, substratum and biotic responses of five central Idaho (USA) streams during the first year following the Mortar Creek fire *International Journal of Wildland Fire* 10: 185-199.

Minshall W.G., Royer T.V., and Robinson C.T. (2001b) Response of Cache Creek macroinvertebrates during the first 10 years following disturbance by the 1998 Yellowstone wildfires *Canadian Journal of Fisheries and Aquatic Sciences volume & pages.*

Minshall W.G. Robinson, C.T. Lawrence, D.E. Andrews, D.A. and Brock, J.T (2001c) Benthic macroinvertebrate assemblages in five central Idaho (USA) streams over a 10-year period following disturbance by wildfire *International Journal of Wildland Fire* 10:201-213

Minshall W.G. (2003) Response of stream benthic macroinvertebrates to fire *Forest and Ecology Management* 178 155-161.

Papas, P.J. (unpub.) Monitoring of fish and aquatic macroinvertebrates following Caledonia Fire 1997/98 Part 1 Assessment of aquatic macroinvertebrate communities and water quality 1998 Freshwater Quality, Department of Natural Resources and Environment, Heidleberg.

Papas, P.J., Nicol J., and Glenane T. (unpub.) Monitoring of fish and aquatic macroinvertebrates and fish communities in February 1999 Freshwater Ecology, Department of natural Resources and Environment , Heidleberg.

Quinn G, and Keough M, (2002) *Experimental Design and Data Analysis for Biologists* Cambridge University Press

Reinfelds, I. and Williams S. (2008) Hydraulic modelling to estimate threshold discharges for sediment entrainment in the Snowy River, Australia. Snowy River Flow Response Monitoring , Department of Water and Energy. Sydney, NSW.

Resh, V.H. Brown, A.V. Covich, A.P. Gurt, M.E. Li, H.W. Minshall, W. Reice, S. Sheldon, A.L. Wallace, B.J. and Wissmar, R.C. (1998) The role of disturbance in stream ecology *Journal of North American Benthological Society* 7 433-455

Rinne, J.N. (1996) Management Briefs – Short-term effects of wildfire on fishes and aquatic macroinvertebrates in south western United States *North American Journal of Fisheries Management* 16: 653-658

Robichaud P.R, (2000) *Forest fire effects on hill slope erosion: What we know*. USDA–Forest Service, Rocky Mountain Research Station, Moscow, Idaho.

Robinson C.T., Uehlinger U., Minshall G.W. (2005) Functional characteristics of wilderness streams twenty years following wildfire *Western North American Naturalist* 65 1-10.

Rose, T.A. and Henderson, D (unpub.) Impact of the December 2002 – March 2003 bushfires on the Snowy River catchment and its effect on the Snowy River Flow Response Monitoring Project. Department of Natural Resources, Cooma, NSW.

Rose, T. A. (in prep.) Changes in geomorphology after the initial flow release to the Snowy River downstream of Jindabyne Dam: Snowy River Recovery: Snowy River Flow Response Monitoring, Department of Water and Energy. Sydney, NSW.

Sokal R and Rohlf J (2001) *Biometry, The principles and practice of statistics in biological research* W.H Freeman & Company, New York, Third edition.

Shakesby R.A and Doerr S.H (2005) Wildfire as a hydrological and geomorphological agent *Earth Science Reviews* 74 pp 269-307.

Vieira N.K.M, Clements, W.H. Guevara, L.S and Jacobs, B.F. (2004) Resistance and resilience of stream insect communities to repeated hydrologic disturbances after wildfire *Freshwater Biology* 49 : 1243-1259.

Appendix 1. Pool Edge Results

Snowy River downstream of the Mowamba River (Site 1)

Figure 4. Pool edge macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A **B**

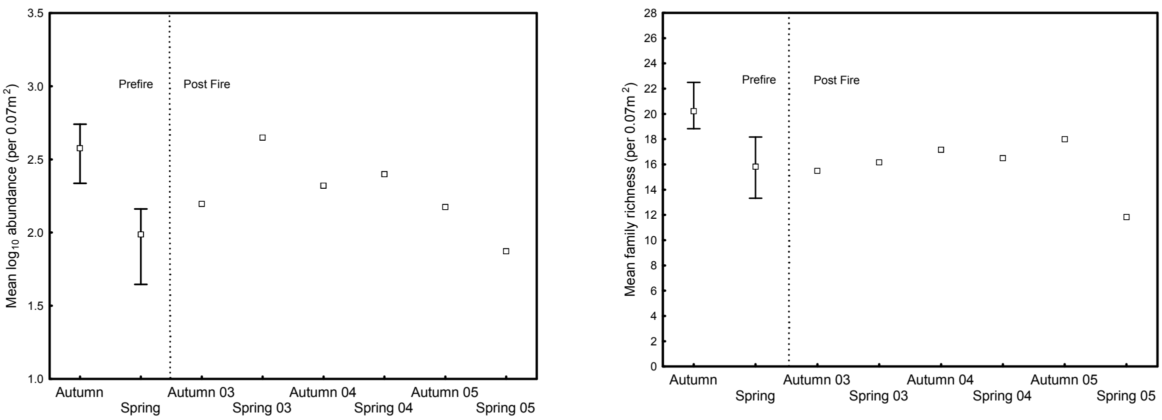


Figure 5. (A) Pool edge nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities

A **B**

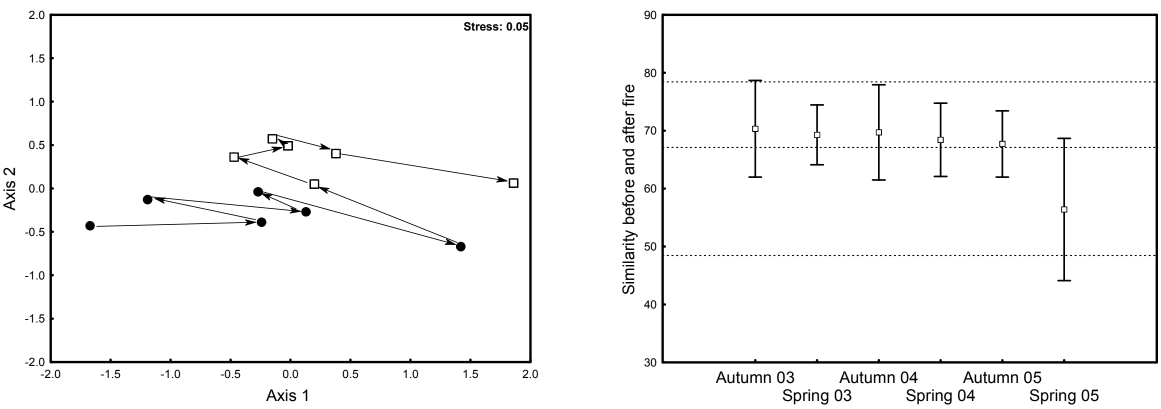


Table 8. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	*t*-value	P value
Autumn pre-fire vs autumn 2003 post-fire	4.60	<0.01
Autumn pre-fire vs autumn 2004 post-fire	3.085	<0.01
Autumn pre-fire vs autumn 2005 post-fire	4.85	<0.01
Spring pre-fire vs spring 2003 post-fire	-8.17	<0.01
Spring pre-fire vs spring 2004 post-fire	-4.88	<0.01
Spring pre-fire vs spring 2005 post-fire	1.47	0.15

B

Planned comparison	*t*-value	P value
Autumn pre-fire vs autumn 2003 post-fire	3.02	<0.01
Autumn pre-fire vs autumn 2004 post-fire	1.95	0.06
Autumn pre-fire vs autumn 2005 post-fire	1.42	0.16
Spring pre-fire vs spring 2003 post-fire	-0.46	0.65
Spring pre-fire vs spring 2004 post-fire	-0.43	0.67
Spring pre-fire vs spring 2005 post-fire	2.55	0.01

Snowy River upstream of Sugarloaf Creek (Site 2)

Figure 6. Pool edge macroinvertebrate (A) mean abundance and(B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A **B**

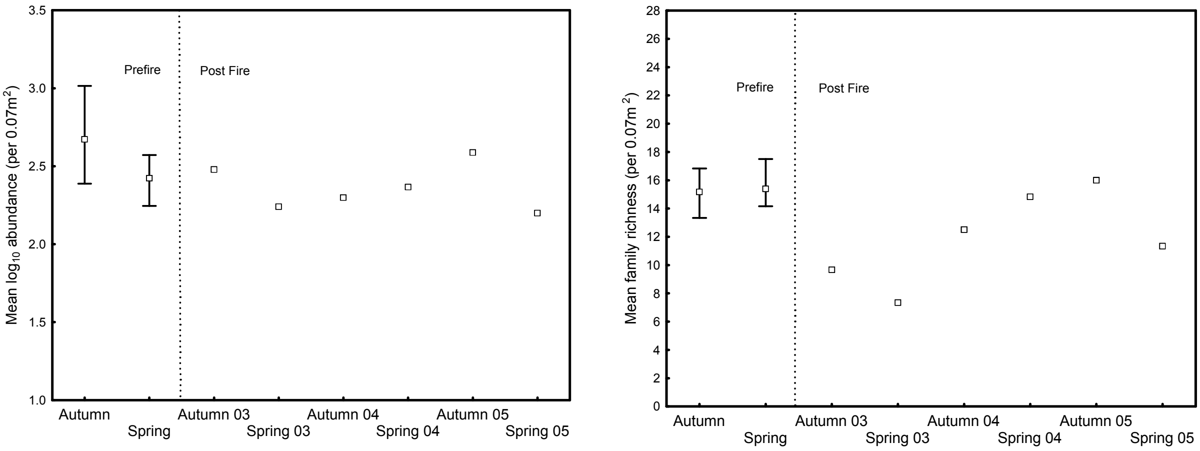


Figure 7. (A) Pool edge nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities

A **B**

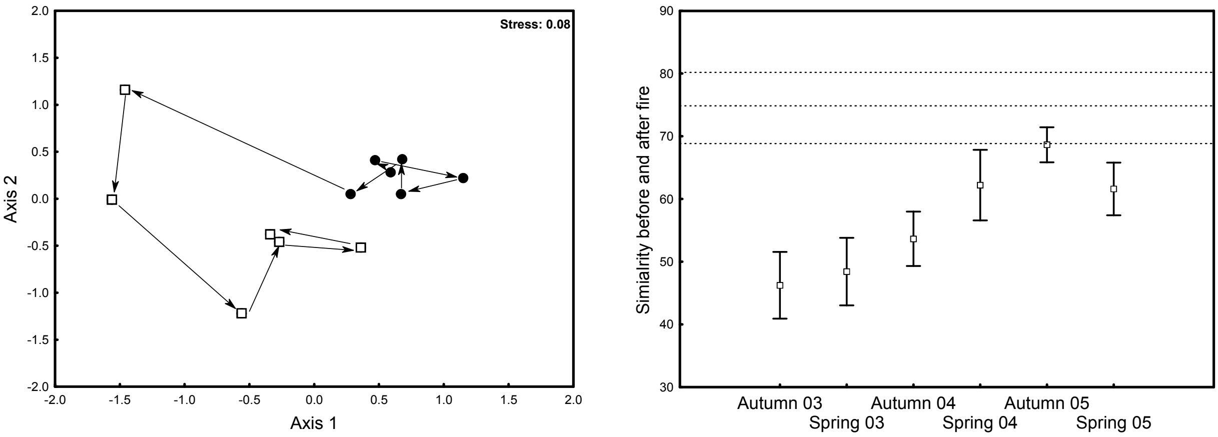


Table 9. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	*t*-value	P value
Autumn pre-fire vs autumn 2003 post-fire	1.31	0.19
Autumn pre-fire vs autumn 2004 post-fire	2.55	0.013
Autumn pre-fire vs autumn 2005 post-fire	0.58	0.57
Spring pre-fire vs spring 2003 post-fire	1.24	0.22
Spring pre-fire vs spring 2004 post-fire	0.39	0.70
Spring pre-fire vs spring 2005 post-fire	1.52	0.13

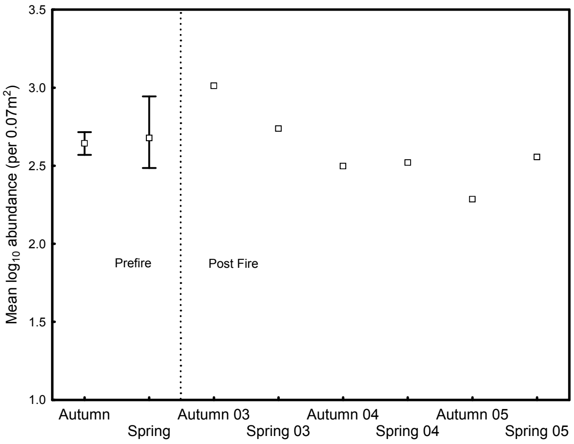
B

Planned comparison	*t*-value	P value
Autumn pre-fire vs autumn 2003 post-fire	3.67	<0.01
Autumn pre-fire vs autumn 2004 post-fire	1.78	0.08
Autumn pre-fire vs autumn 2005 post-fire	-0.56	0.58
Spring pre-fire vs spring 2003 post-fire	5.38	<0.01
Spring pre-fire vs spring 2004 post-fire	0.37	0.71
Spring pre-fire vs spring 2005 post-fire	2.71	<0.01

Snowy River at Rockwell (Site 3)

Figure 8. Pool edge macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A



B

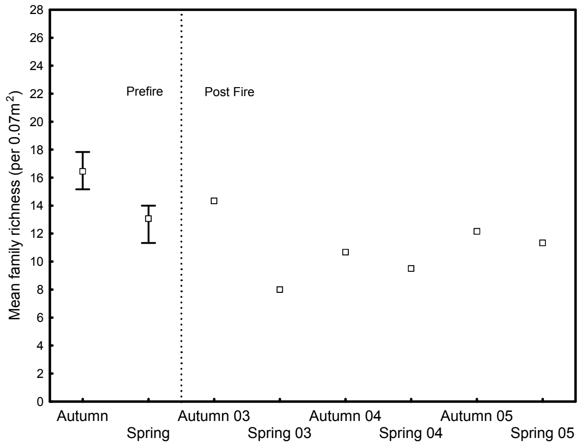
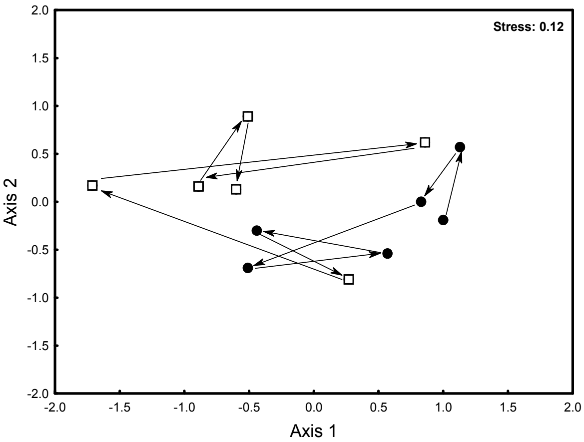


Figure 9. (A) Pool edge nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A



B

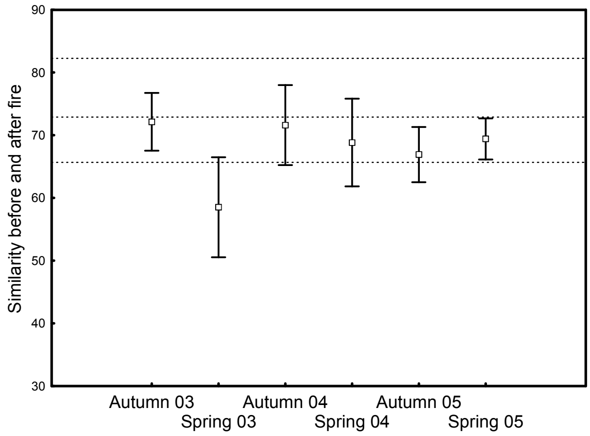


Table 10. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	-3.24	<0.01
Autumn pre-fire vs autumn 2004 post-fire	1.28	0.20
Autumn pre-fire vs autumn 2005 post-fire	3.15	<0.01
Spring pre-fire vs spring 2003 post-fire	-0.52	0.60
Spring pre-fire vs spring 2004 post-fire	1.39	0.17
Spring pre-fire vs spring 2005 post-fire	1.07	0.29

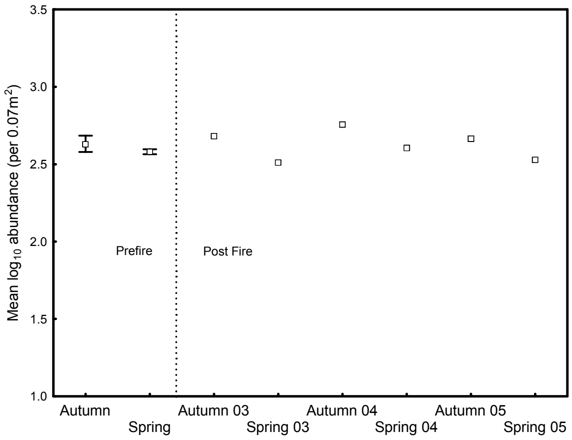
B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	1.71	0.09
Autumn pre-fire vs autumn 2004 post-fire	4.69	<0.01
Autumn pre-fire vs autumn 2005 post-fire	3.47	<0.01
Spring pre-fire vs spring 2003 post-fire	4.11	<0.01
Spring pre-fire vs spring 2004 post-fire	2.89	<0.01
Spring pre-fire vs spring 2005 post-fire	1.40	0.17

Snowy River downstream of Blackburn Creek (Site 4)

Figure 10. Pool edge macroinvertebrate (A) mean abundance (B) and mean family richness (B) for pre and post wildfire. Error bars indicate range of pre-fire observations.

A



B

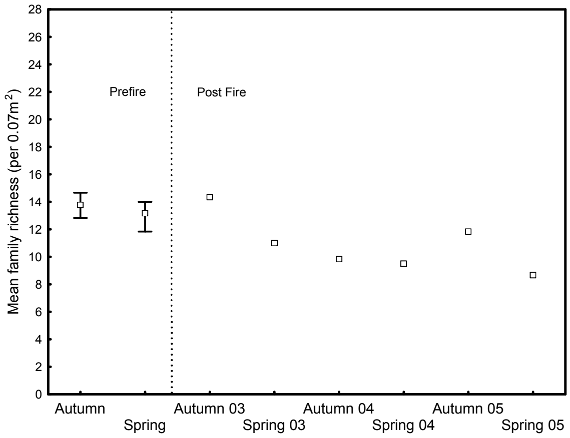
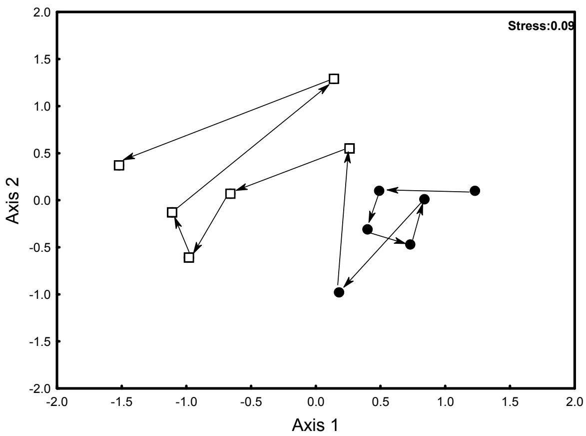


Figure 11. (A) Pool edge nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A



B

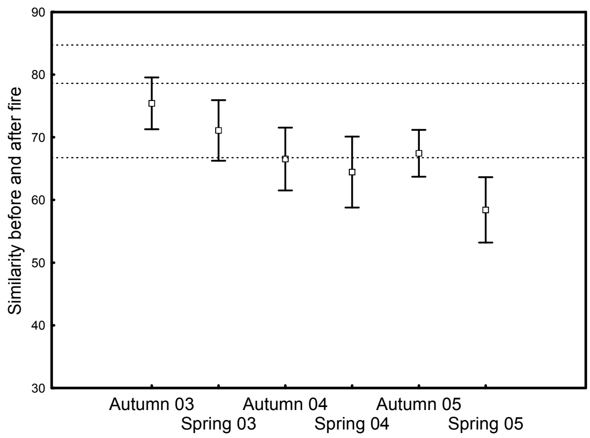


Table 11. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	-0.54	0.59
Autumn pre-fire vs autumn 2004 post-fire	-1.32	0.19
Autumn pre-fire vs autumn 2005 post-fire	-0.37	0.71
Spring pre-fire vs spring 2003 post-fire	0.72	0.47
Spring pre-fire vs spring 2004 post-fire	-0.25	0.80
Spring pre-fire vs spring 2005 post-fire	0.54	0.59

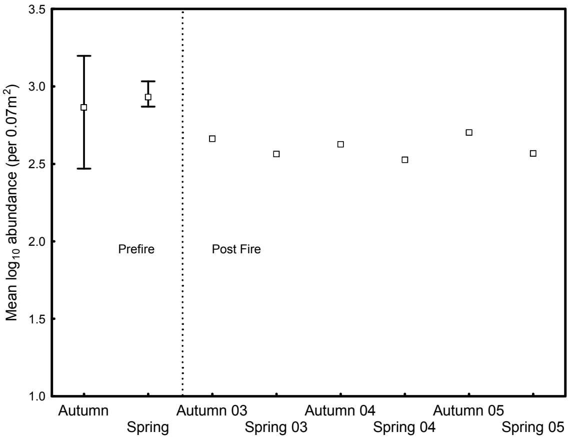
B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	-0.48	0.63
Autumn pre-fire vs autumn 2004 post-fire	3.41	<0.01
Autumn pre-fire vs autumn 2005 post-fire	1.68	0.097
Spring pre-fire vs spring 2003 post-fire	1.87	0.065
Spring pre-fire vs spring 2004 post-fire	3.17	<0.01
Spring pre-fire vs spring 2005 post-fire	3.89	<0.01

Snowy River at Willis (Site 6)

Figure 12. Pool edge macroinvertebrate (A) mean abundance and(B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A



B

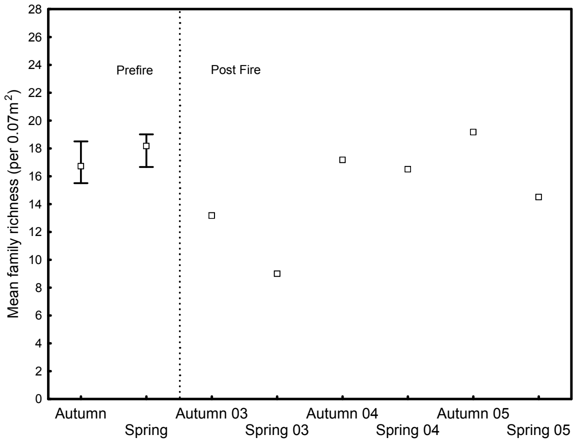
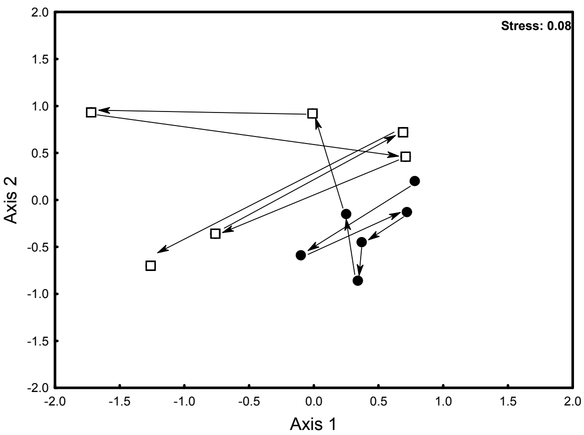


Figure 13. (A) Pool edge nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities

A



B

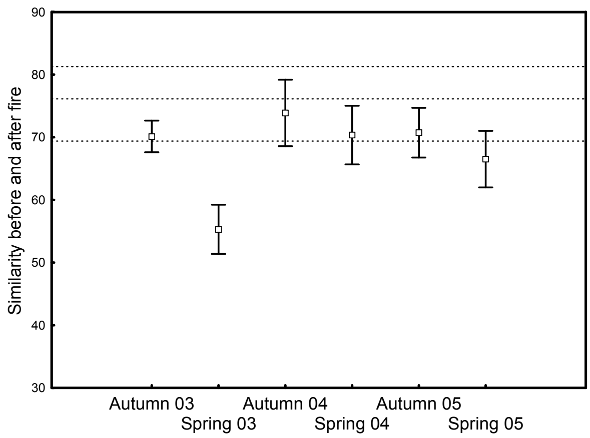


Table 12. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	2.03	0.047
Autumn pre-fire vs autumn 2004 post-fire	2.40	0.019
Autumn pre-fire vs autumn 2005 post-fire	1.63	0.11
Spring pre-fire vs spring 2003 post-fire	3.70	<0.01
Spring pre-fire vs spring 2004 post-fire	4.07	<0.01
Spring pre-fire vs spring 2005 post-fire	3.65	<0.01

B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	2.64	0.01
Autumn pre-fire vs autumn 2004 post-fire	-0.33	0.74
Autumn pre-fire vs autumn 2005 post-fire	-1.81	0.07
Spring pre-fire vs spring 2003 post-fire	6.80	<0.01
Spring pre-fire vs spring 2004 post-fire	1.23	0.22
Spring pre-fire vs spring 2005 post-fire	2.72	<0.01

Snowy River at Mckillops Bridge (Site 7)

Figure 14. Pool edge macroinvertebrate (A) mean abundance and(B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A **B**

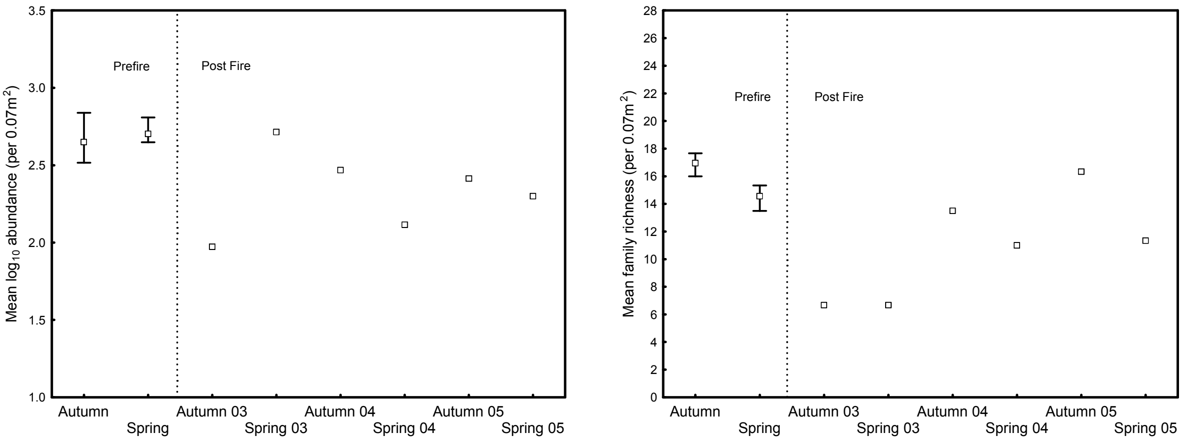


Figure 15. (A) Pool edge nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A **B**

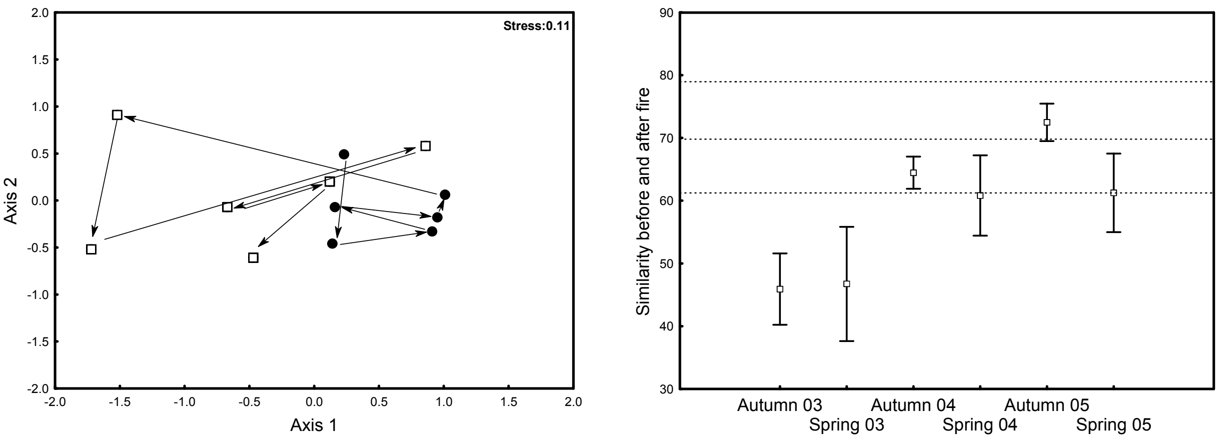


Table 13. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	5.28	<0.01
Autumn pre-fire vs autumn 2004 post-fire	1.42	0.16
Autumn pre-fire vs autumn 2005 post-fire	1.85	0.07
Spring pre-fire vs spring 2003 post-fire	-0.10	0.92
Spring pre-fire vs spring 2004 post-fire	4.58	<0.01
Spring pre-fire vs spring 2005 post-fire	3.14	<0.01

B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	8.42	<0.01
Autumn pre-fire vs autumn 2004 post-fire	2.82	<0.01
Autumn pre-fire vs autumn 2005 post-fire	0.50	0.62
Spring pre-fire vs spring 2003 post-fire	6.46	<0.01
Spring pre-fire vs spring 2004 post-fire	2.91	<0.01
Spring pre-fire vs spring 2005 post-fire	2.64	0.01

Mowamba River (Site 12)

Figure 16. Pool edge macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A **B**

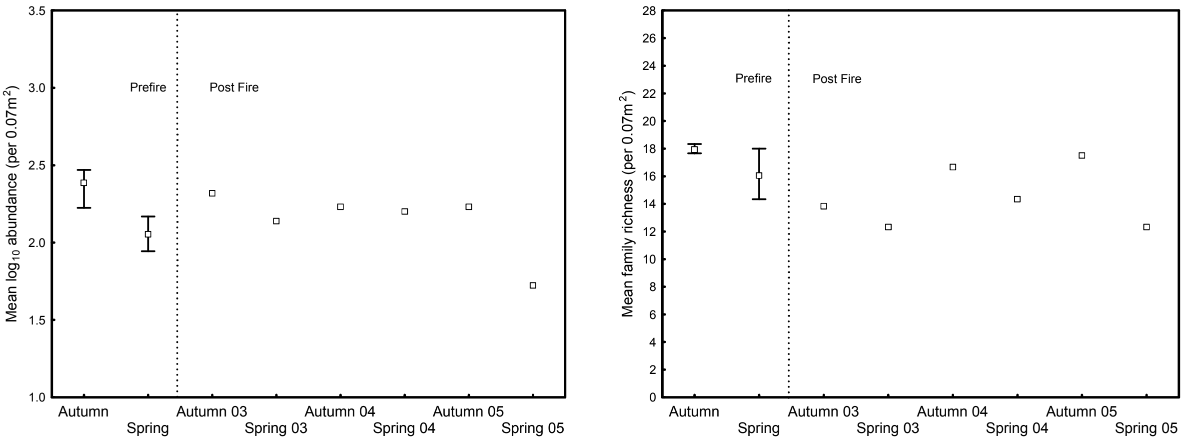


Figure 17. (A) Pool edge nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A **B**

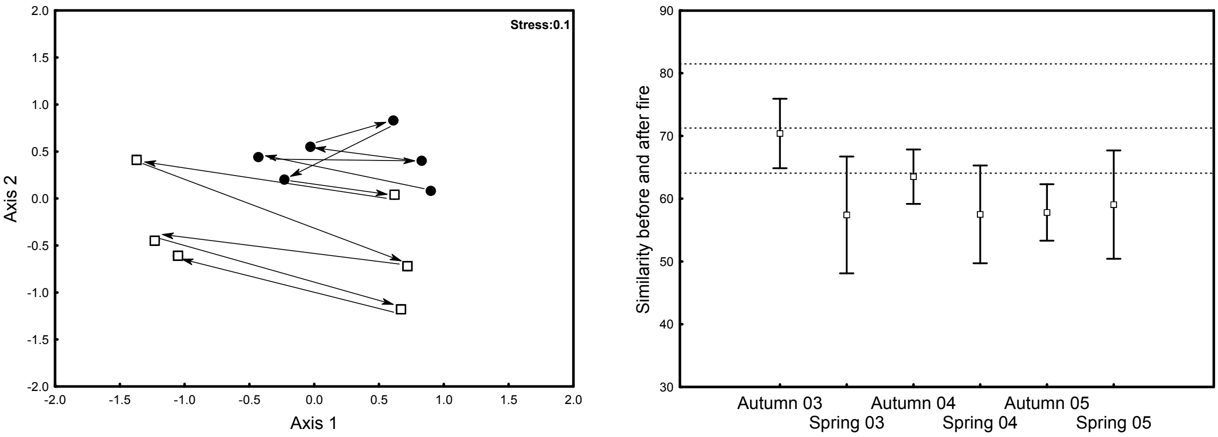


Table 14. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	0.54	0.59
Autumn pre-fire vs autumn 2004 post-fire	1.23	0.22
Autumn pre-fire vs autumn 2005 post-fire	1.23	0.22
Spring pre-fire vs spring 2003 post-fire	-0.68	0.50
Spring pre-fire vs spring 2004 post-fire	-1.16	0.25
Spring pre-fire vs spring 2005 post-fire	2.62	0.01

B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	2.83	<0.01
Autumn pre-fire vs autumn 2004 post-fire	0.88	0.38
Autumn pre-fire vs autumn 2005 post-fire	0.31	0.76
Spring pre-fire vs spring 2003 post-fire	2.56	0.01
Spring pre-fire vs spring 2004 post-fire	1.19	0.24
Spring pre-fire vs spring 2005 post-fire	2.56	0.01

Thredbo River (Site 13)

Figure 18. Pool edge macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A **B**

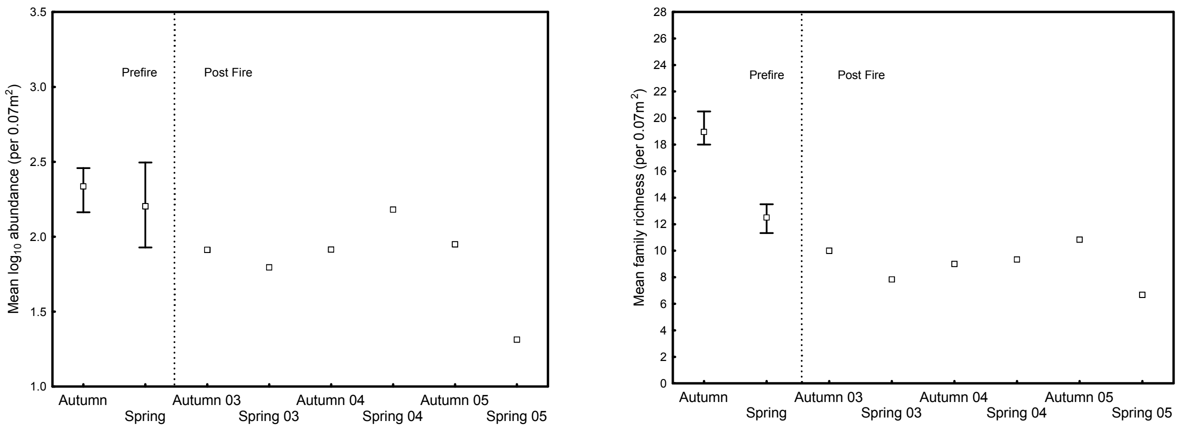


Figure 19. (A) Pool edge nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A **B**

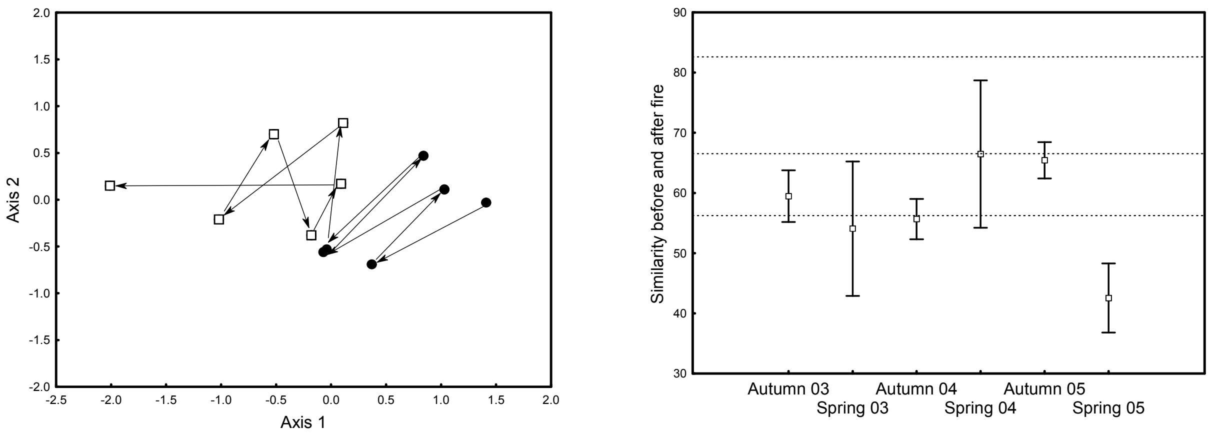


Table 15. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	3.01	<0.01
Autumn pre-fire vs autumn 2004 post-fire	2.99	<0.01
Autumn pre-fire vs autumn 2005 post-fire	2.56	0.013
Spring pre-fire vs spring 2003 post-fire	2.89	<0.01
Spring pre-fire vs spring 2004 post-fire	0.16	0.88
Spring pre-fire vs spring 2005 post-fire	6.31	<0.01

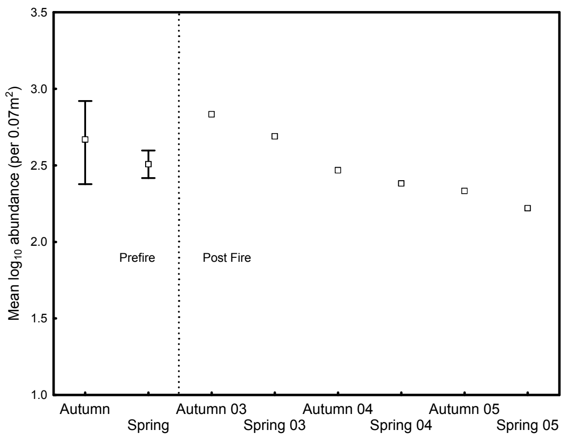
B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	5.06	<0.01
Autumn pre-fire vs autumn 2004 post-fire	5.63	<0.01
Autumn pre-fire vs autumn 2005 post-fire	4.59	<0.01
Spring pre-fire vs spring 2003 post-fire	2.64	0.01
Spring pre-fire vs spring 2004 post-fire	1.79	0.08
Spring pre-fire vs spring 2005 post-fire	3.30	<0.01

Cann River (Site 25)

Figure 20. Pool edge macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A



B

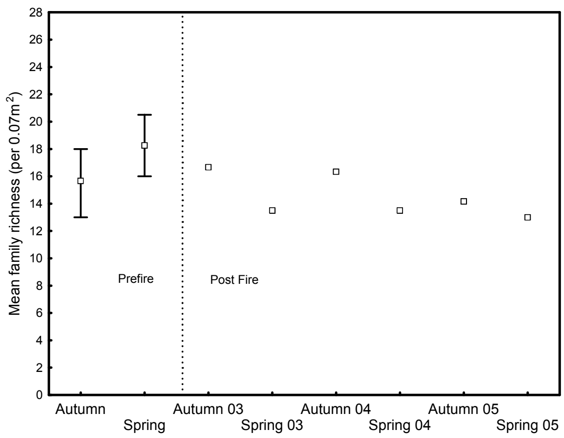
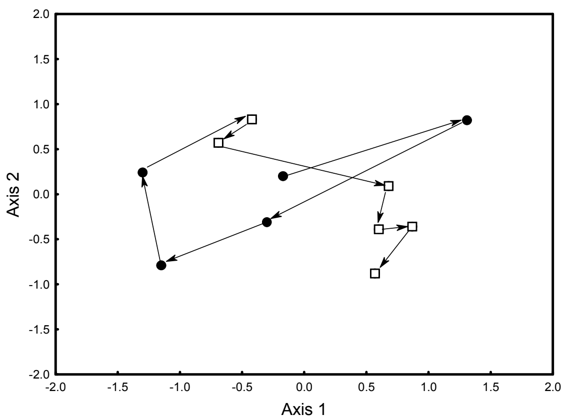


Figure 21. (A) Pool edge nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A



B

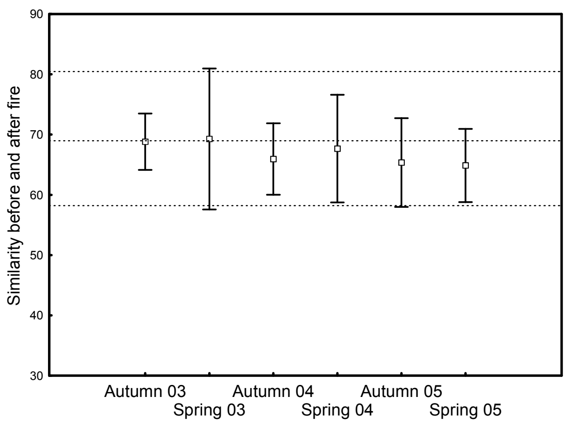


Table 16. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	-2.85	<0.01
Autumn pre-fire vs autumn 2004 post-fire	0.34	0.74
Autumn pre-fire vs autumn 2005 post-fire	1.52	0.13
Spring pre-fire vs spring 2003 post-fire	-0.19	0.85
Spring pre-fire vs spring 2004 post-fire	2.65	0.01
Spring pre-fire vs spring 2005 post-fire	4.15	<0.01

B

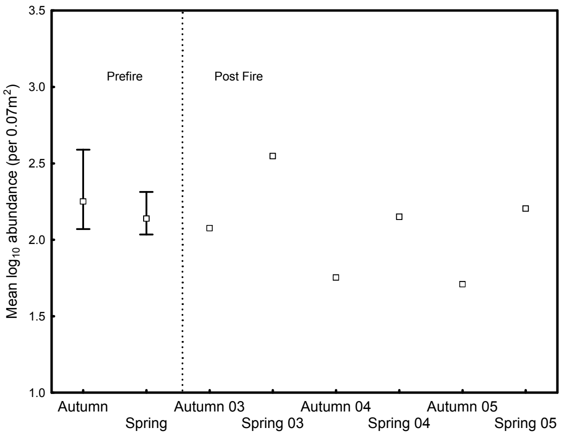
Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	1.20	0.23
Autumn pre-fire vs autumn 2004 post-fire	1.46	0.15
Autumn pre-fire vs autumn 2005 post-fire	3.11	<0.01
Spring pre-fire vs spring 2003 post-fire	1.75	0.09
Spring pre-fire vs spring 2004 post-fire	1.75	0.09
Spring pre-fire vs spring 2005 post-fire	2.15	0.04

Appendix 2 Riffle Results

Snowy River downstream of the Mowamba River (Site 1)

Figure 22. Riffle macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A



B

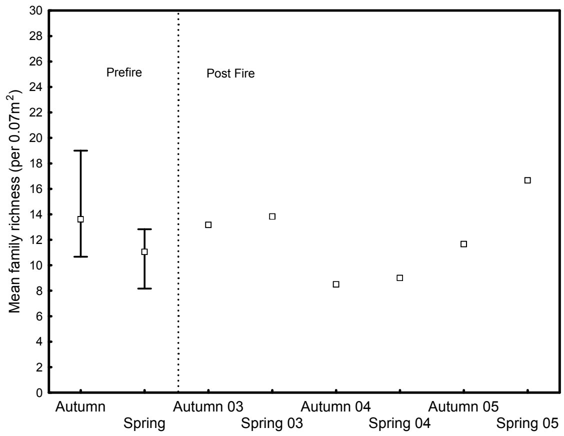
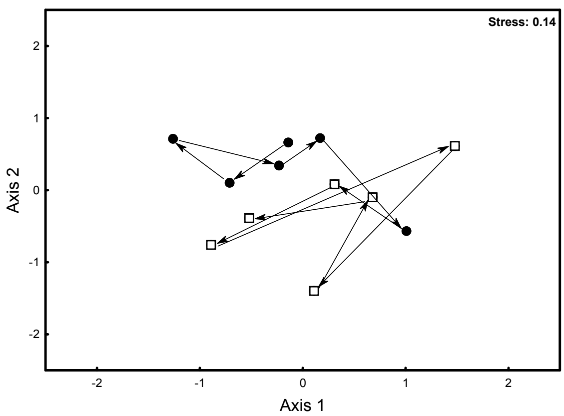


Figure 23. (A) Riffle nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A



B

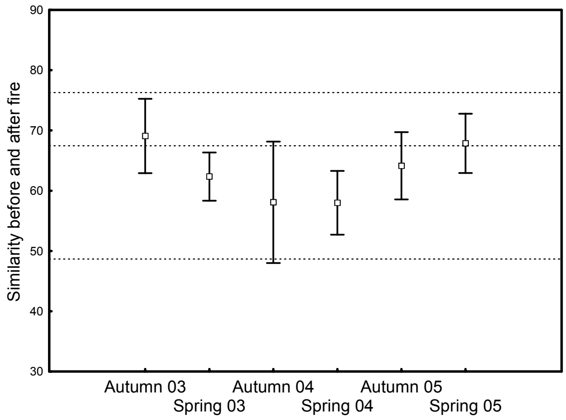


Table 17. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	1.13	0.26
Autumn pre-fire vs autumn 2004 post-fire	3.21	<0.01
Autumn pre-fire vs autumn 2005 post-fire	3.50	<0.01
Spring pre-fire vs spring 2003 post-fire	-2.64	0.01
Spring pre-fire vs spring 2004 post-fire	-0.08	0.94
Spring pre-fire vs spring 2005 post-fire	-0.43	0.67

B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	0.29	0.77
Autumn pre-fire vs autumn 2004 post-fire	3.31	<0.01
Autumn pre-fire vs autumn 2005 post-fire	1.26	0.21
Spring pre-fire vs spring 2003 post-fire	-1.80	0.08
Spring pre-fire vs spring 2004 post-fire	1.33	0.19
Spring pre-fire vs spring 2005 post-fire	-3.64	<0.01

Snowy River upstream of Sugarloaf Creek (Site 2)

Figure 24. Riffle macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A **B**

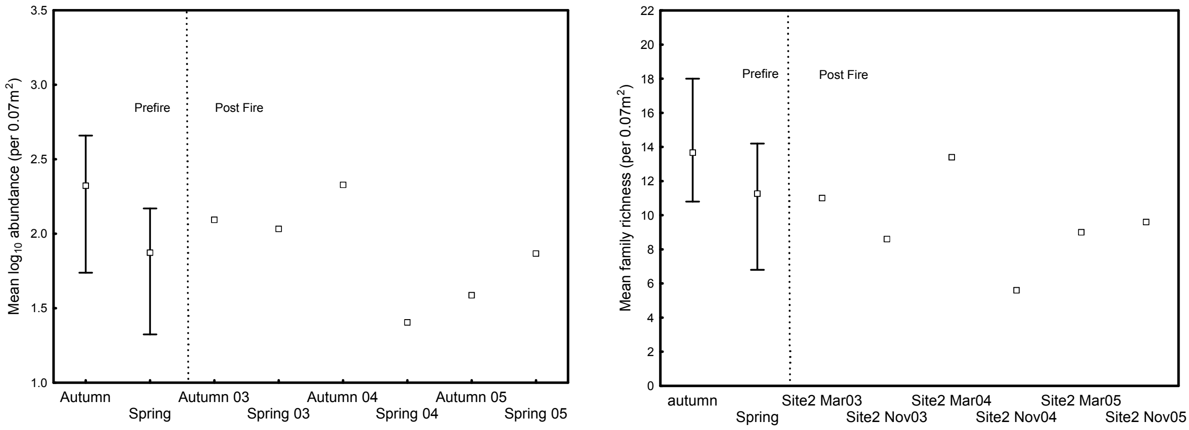


Figure 25. (A) Riffle nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A **B**

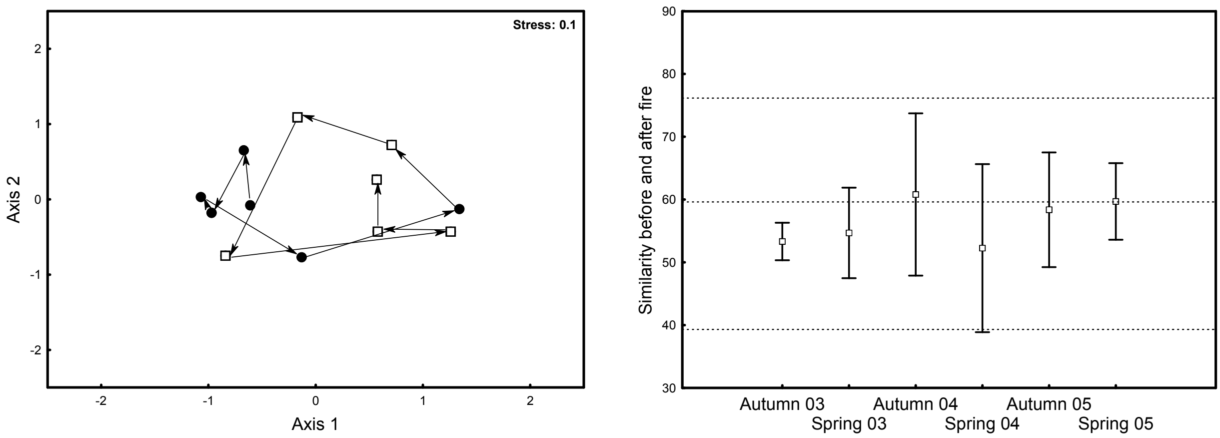


Table 18. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	0.90	0.37
Autumn pre-fire vs autumn 2004 post-fire	-0.23	0.82
Autumn pre-fire vs autumn 2005 post-fire	3.35	<0.01
Spring pre-fire vs spring 2003 post-fire	-0.68	0.50
Spring pre-fire vs spring 2004 post-fire	2.38	0.02
Spring pre-fire vs spring 2005 post-fire	0.13	0.90

B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	1.34	0.18
Autumn pre-fire vs autumn 2004 post-fire	-0.84	0.41
Autumn pre-fire vs autumn 2005 post-fire	2.3	0.02
Spring pre-fire vs spring 2003 post-fire	1.26	0.21
Spring pre-fire vs spring 2004 post-fire	3.19	<0.01
Spring pre-fire vs spring 2005 post-fire	0.82	0.42

Snowy River at Rockwell (Site 3)

Figure 26. Riffle macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A **B**

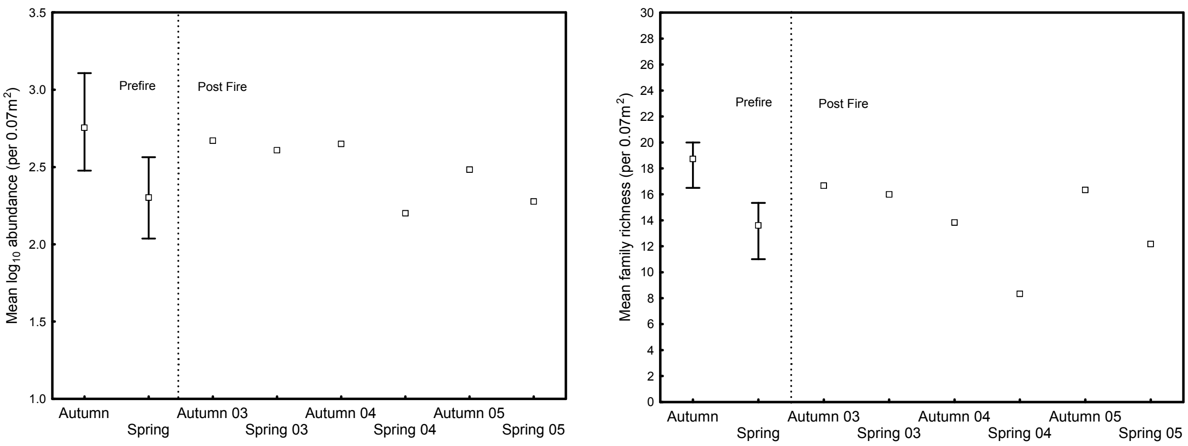


Figure 27. (A) Riffle nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A **B**

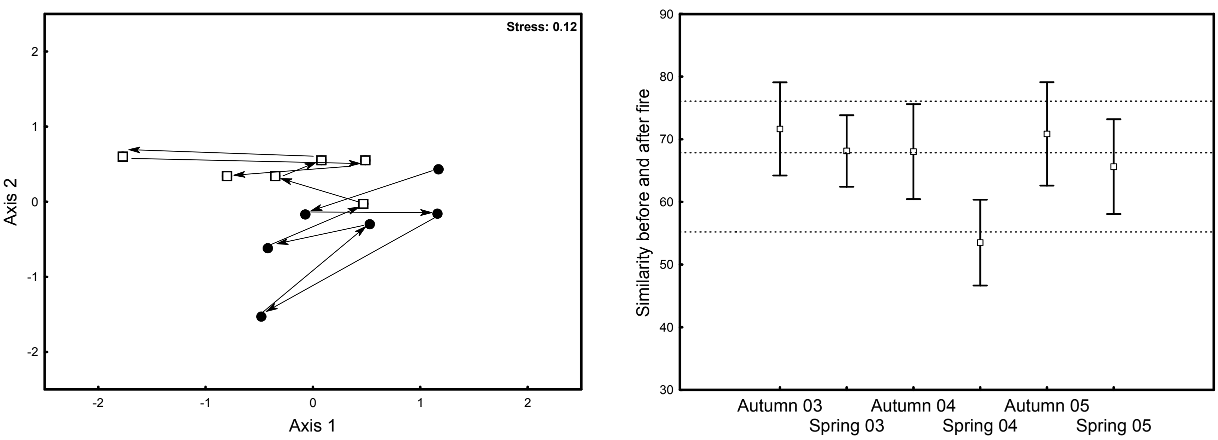


Table 19. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	0.58	0.56
Autumn pre-fire vs autumn 2004 post-fire	0.73	0.47
Autumn pre-fire vs autumn 2005 post-fire	1.88	0.07
Spring pre-fire vs spring 2003 post-fire	-2.11	0.04
Spring pre-fire vs spring 2004 post-fire	0.71	0.48
Spring pre-fire vs spring 2005 post-fire	0.18	0.86

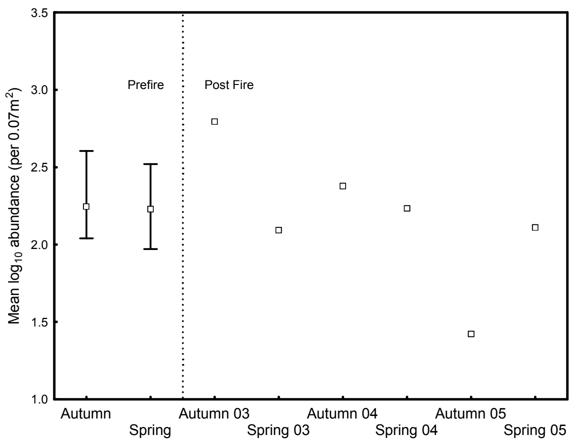
B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	1.21	0.23
Autumn pre-fire vs autumn 2004 post-fire	2.88	<0.01
Autumn pre-fire vs autumn 2005 post-fire	1.41	0.16
Spring pre-fire vs spring 2003 post-fire	-1.41	0.16
Spring pre-fire vs spring 2004 post-fire	3.11	<0.01
Spring pre-fire vs spring 2005 post-fire	0.85	0.40

Snowy River downstream of Blackburn Creek (Site 4)

Figure 28. Riffle macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A



B

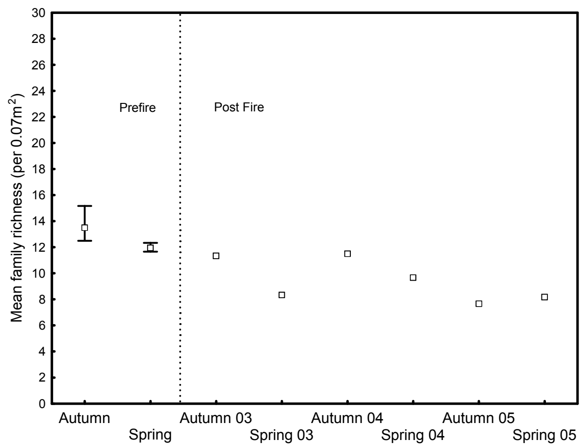
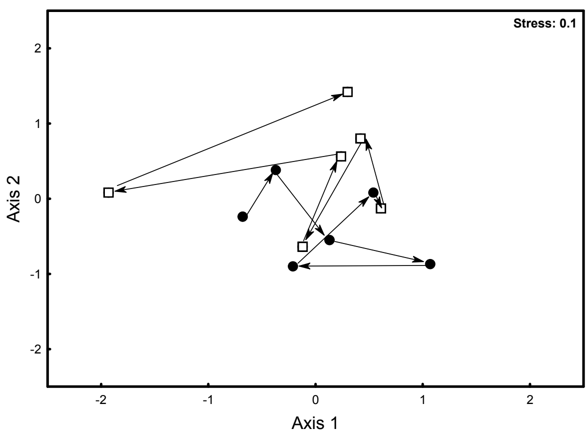


Figure 29. (A) Riffle nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A



B

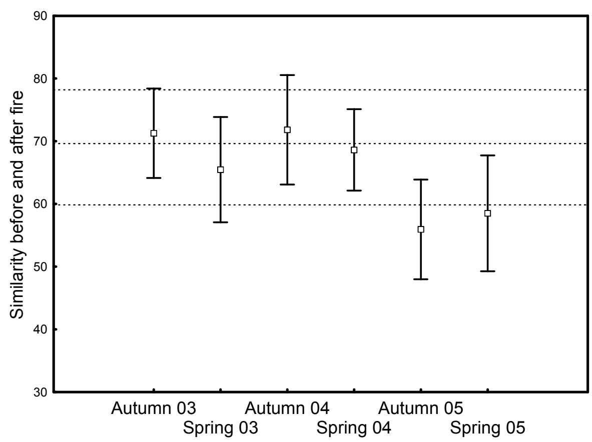


Table 20. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	-4.05	<0.01
Autumn pre-fire vs autumn 2004 post-fire	-0.98	0.33
Autumn pre-fire vs autumn 2005 post-fire	6.08	<0.01
Spring pre-fire vs spring 2003 post-fire	1.00	0.32
Spring pre-fire vs spring 2004 post-fire	-0.04	0.97
Spring pre-fire vs spring 2005 post-fire	0.87	0.39

B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	1.74	0.09
Autumn pre-fire vs autumn 2004 post-fire	1.60	0.11
Autumn pre-fire vs autumn 2005 post-fire	4.68	<0.01
Spring pre-fire vs spring 2003 post-fire	2.89	<0.01
Spring pre-fire vs spring 2004 post-fire	1.83	0.07
Spring pre-fire vs spring 2005 post-fire	3.03	<0.01

Snowy River at Willis (Site 6)

Figure 30. Riffle macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A **B**

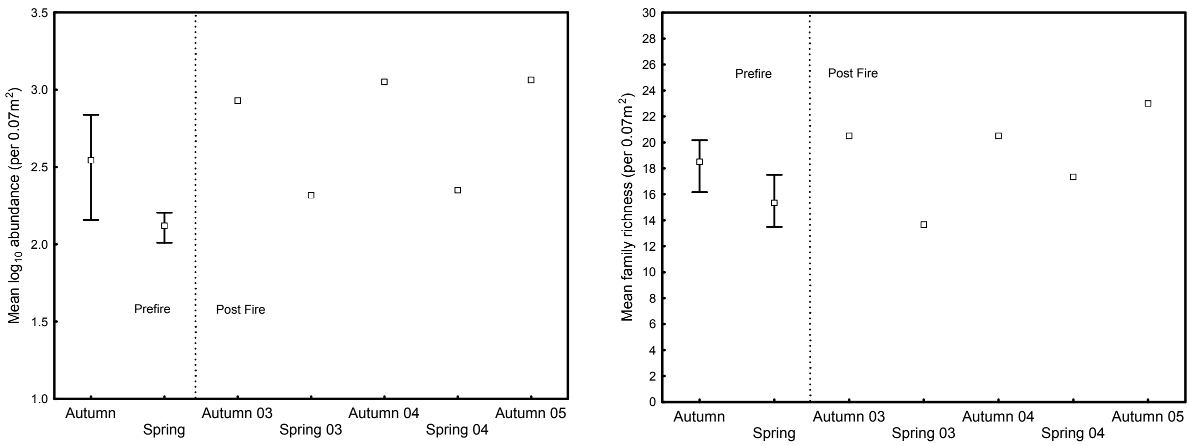


Figure 31. (A) Riffle nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A **B**

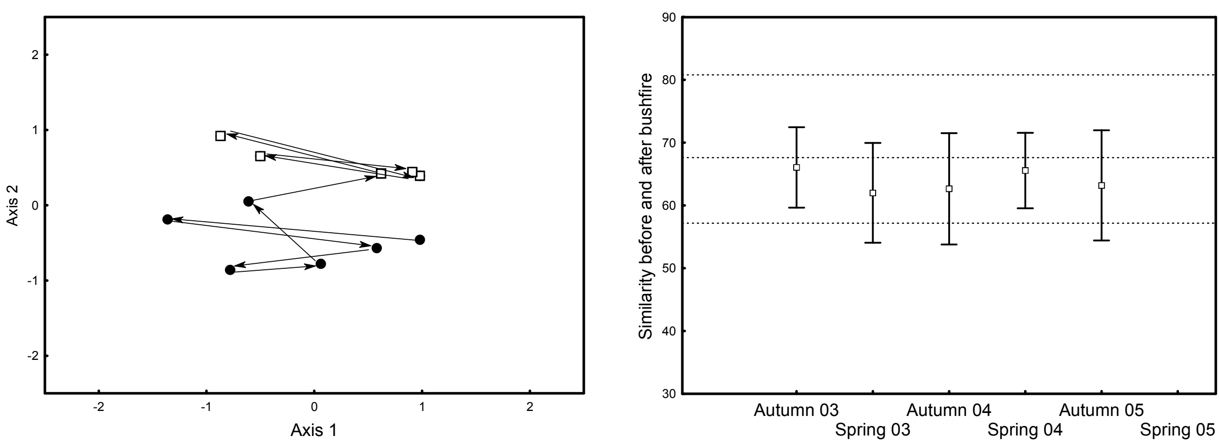


Table 21. Planned comparisons testing differences for (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	-3.39	<0.01
Autumn pre-fire vs autumn 2004 post-fire	-4.47	<0.01
Autumn pre-fire vs autumn 2005 post-fire	-4.58	<0.01
Spring pre-fire vs spring 2003 post-fire	-1.73	0.09
Spring pre-fire vs spring 2004 post-fire	-2.01	0.05

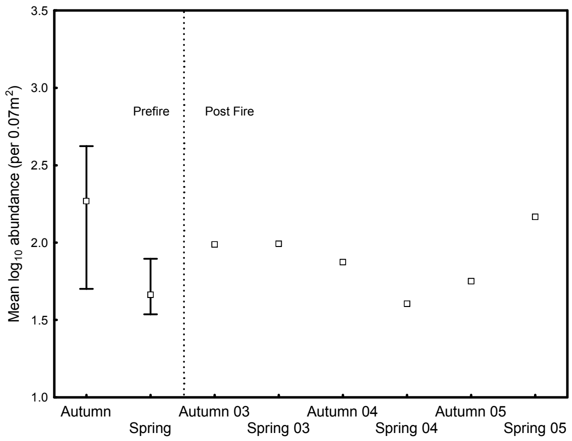
B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	-1.48	0.14
Autumn pre-fire vs autumn 2004 post-fire	-1.48	0.14
Autumn pre-fire vs autumn 2005 post-fire	0.86	0.39
Spring pre-fire vs spring 2003 post-fire	1.23	0.22
Spring pre-fire vs spring 2004 post-fire	-5.68	<0.01

Snowy River at Mckillops Bridge (Site 7)

Figure 32. Riffle macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A



B

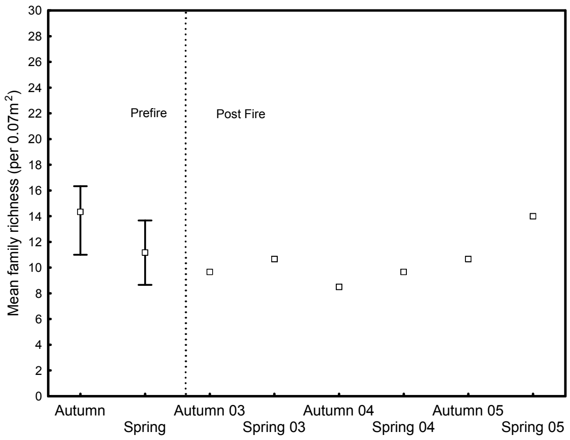
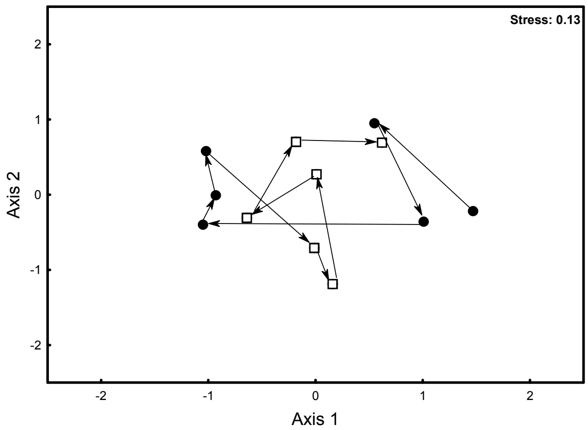


Figure 33. (A) Riffle nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A



B

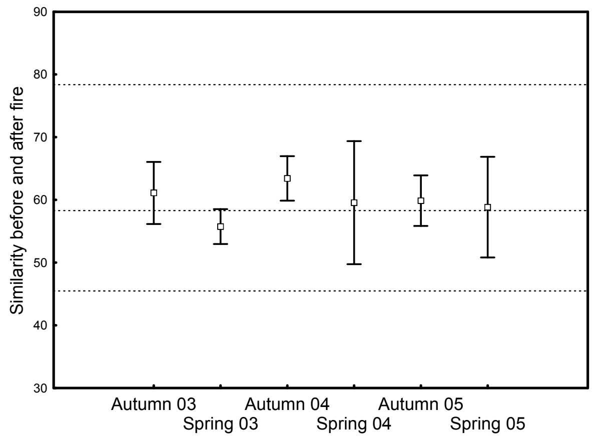


Table 22. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	2.20	0.03
Autumn pre-fire vs autumn 2004 post-fire	3.09	<0.01
Autumn pre-fire vs autumn 2005 post-fire	4.07	<0.01
Spring pre-fire vs spring 2003 post-fire	-2.59	0.01
Spring pre-fire vs spring 2004 post-fire	0.45	0.66
Spring pre-fire vs spring 2005 post-fire	-3.95	<0.01

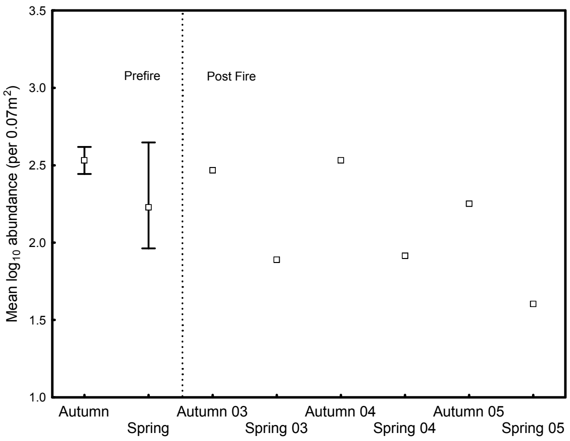
B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	3.42	<0.01
Autumn pre-fire vs autumn 2004 post-fire	4.27	<0.01
Autumn pre-fire vs autumn 2005 post-fire	2.69	<0.01
Spring pre-fire vs spring 2003 post-fire	0.37	0.72
Spring pre-fire vs spring 2004 post-fire	1.10	0.28
Spring pre-fire vs spring 2005 post-fire	-2.08	0.04

Mowamba River (Site 12)

Figure 34. Riffle macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A



B

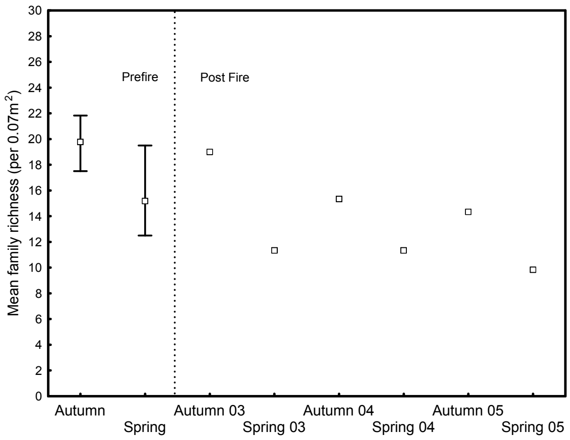
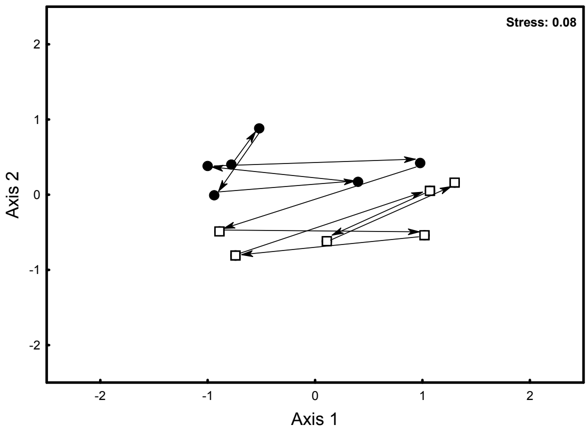


Figure 35. (A) Riffle nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A



B

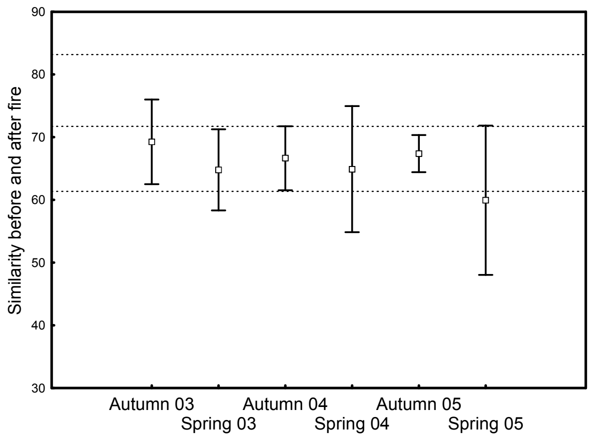


Table 23. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	0.38	0.71
Autumn pre-fire vs autumn 2004 post-fire	-0.00	1.00.
Autumn pre-fire vs autumn 2005 post-fire	1.65	0.10
Spring pre-fire vs spring 2003 post-fire	1.99	0.05
Spring pre-fire vs spring 2004 post-fire	1.84	0.07
Spring pre-fire vs spring 2005 post-fire	3.66	<0.01

B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	0.49	0.62
Autumn pre-fire vs autumn 2004 post-fire	2.82	<0.01
Autumn pre-fire vs autumn 2005 post-fire	3.45	<0.01
Spring pre-fire vs spring 2003 post-fire	2.43	0.018
Spring pre-fire vs spring 2004 post-fire	2.43	0.02
Spring pre-fire vs spring 2005 post-fire	3.38	<0.01

Thredbo River (Site 13)

Figure 36. Riffle macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A **B**

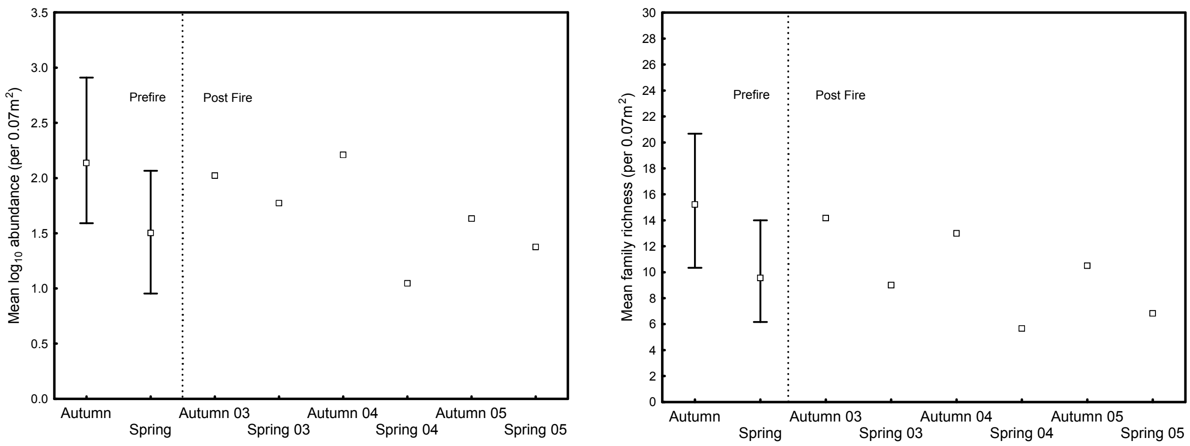


Figure 37. (A) Riffle nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A **B**

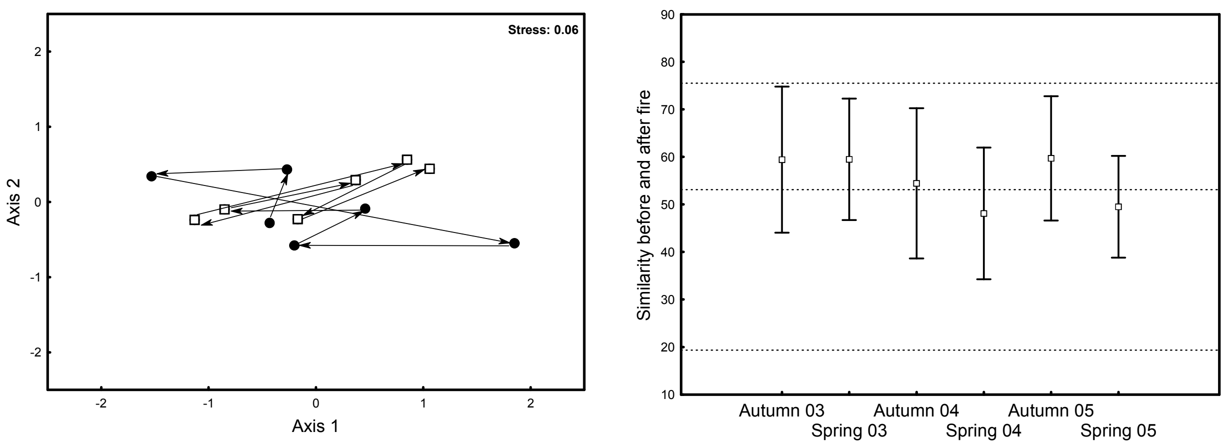


Table 24. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	0.66	0.51
Autumn pre-fire vs autumn 2004 post-fire	-0.42	0.68
Autumn pre-fire vs autumn 2005 post-fire	2.89	<0.01
Spring pre-fire vs spring 2003 post-fire	-1.55	0.13
Spring pre-fire vs spring 2004 post-fire	2.61	0.01
Spring pre-fire vs spring 2005 post-fire	0.72	0.47

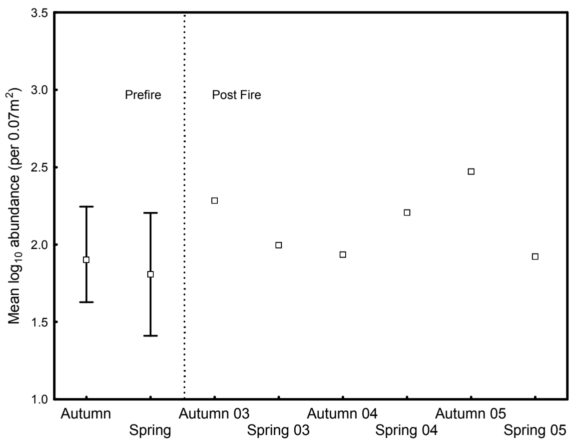
B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	0.65	0.52
Autumn pre-fire vs autumn 2004 post-fire	1.37	0.18
Autumn pre-fire vs autumn 2005 post-fire	2.91	<0.01
Spring pre-fire vs spring 2003 post-fire	0.34	0.73
Spring pre-fire vs spring 2004 post-fire	2.40	0.02
Spring pre-fire vs spring 2005 post-fire	1.70	0.01

Cann River (Site 25)

Figure 38. Riffle macroinvertebrate (A) mean abundance and (B) mean family richness for pre and post wildfire. Error bars indicate range of pre-fire observations.

A



B

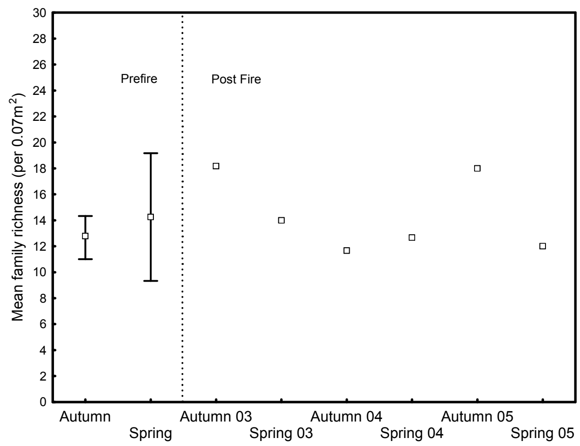
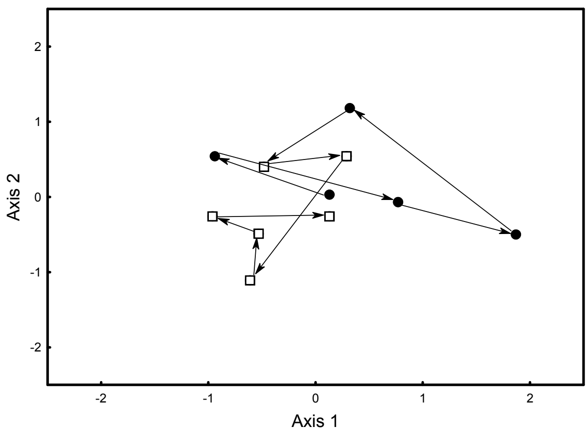


Figure 39. (A) Riffle nMDS ordination. The (●) symbol represents before the wildfire and (□) represents the seasons sampled after. Arrows denote macroinvertebrate community through time. (B) Mean plot of Bray Curtis similarity measure before and after fire with 95% confidence limits. The dotted lines represent the mean of the pre-fire similarities and their minimum and maximum similarities.

A



B

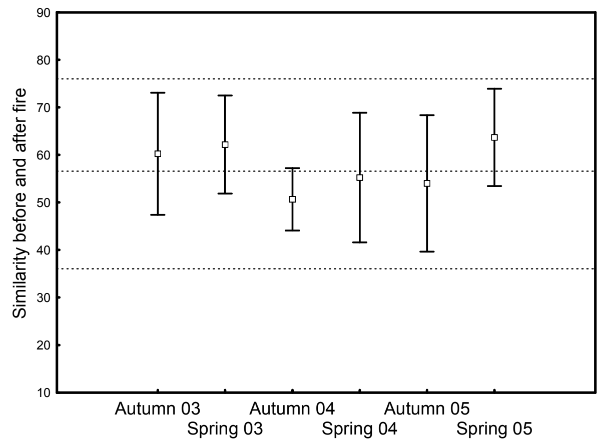


Table 25. Planned comparisons testing differences in (A) mean abundance and (B) mean family richness.

A

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	-2.87	<0.01
Autumn pre-fire vs autumn 2004 post-fire	-0.76	0.45
Autumn pre-fire vs autumn 2005 post-fire	-4.00	<0.01
Spring pre-fire vs spring 2003 post-fire	-0.61	0.55
Spring pre-fire vs spring 2004 post-fire	-1.96	0.06
Spring pre-fire vs spring 2005 post-fire	-0.14	0.89

B

Planned comparison	t-value	P value
Autumn pre-fire vs autumn 2003 post-fire	-1.99	0.05
Autumn pre-fire vs autumn 2004 post-fire	1.31	0.19
Autumn pre-fire vs autumn 2005 post-fire	-1.91	0.06
Spring pre-fire vs spring 2003 post-fire	-0.66	0.51
Spring pre-fire vs spring 2004 post-fire	0.06	0.95
Spring pre-fire vs spring 2005 post-fire	0.42	0.68