SNOWY RIVER RECOVERY

SNOWY RIVER FLOW RESPONSE MONITORING

RESPONSE OF AQUATIC MACROINVERTEBRATES TO THE FIRST ENVIRONMENTAL FLOW REGIME IN THE SNOWY RIVER

NOVEMBER 2007

NSW Government
Department of Water & Energy

ACKNOWLEDGEMENTS

The Snowy River Recovery Program has been funded by the Australian, New South Wales and Victorian Governments.

The authors, Andrew Brooks, Matthew Russell and Robyn Bevitt would like to thank Teresa Rose, Tim Haeusler, Dayle Green, Sue Pritchard, Simon Williams, Tim Fletcher, Danny Henderson and Graeme Enders for assistance in the field and logistic support. Thanks to Bruce Chessman, Sam Lake and Simon Williams for reviewing the report.

This document should be referenced as follows:

Brooks, A Russell, M and Bevitt, R. (2007). *Response to aquatic macroinvertebrates to the first environmental flow regime in the Snowy River.* Snowy River Recovery: Snowy River Flow Response Monitoring, NSW Department of Water and Energy.

ISSN 1449 8022

ISBN 978 0 7347 5927 6

DWE 07_O69

November 2007

(First published July 2007)

Summary

The construction of the Snowy Mountains Scheme (SMS) between 1955 and 1967 for power generation and to provide water to the Murrumbidgee Irrigation Area diverted approximately 96% of flow from the Snowy River downstream of Jindabyne Dam as measured at Dalgety. The first environmental flow releases to the Snowy River from decommissioning Mowamba River aqueduct occurred on 28 August 2002 and continued throughout the study. The Snowy River Environmental Flow Response Monitoring Project was established in 2000 to provide a physical, chemical and biological assessment of the river and quantify the changes, if any, caused by the implementation of environmental flows. This report documents the effects of environmental flows on aquatic macroinvertebrate assemblages of the Snowy River and incorporates data collected from autumn 2000 to autumn 2005.

The median daily flows in the upland macro-reach of the Snowy River increased by 50% after the provision of environmental flow releases from the decommissioning of Mowamba River aqueduct. These flows were still substantially lower than the simulated natural flows in the Snowy River for the same period (approximately 94% lower) and about 30% of the flow in the corresponding reference sites. The median daily flows in the midland and lowland macro-reaches of the Snowy River and reference sites reduced by approximately 40% during the period with EFR because of the prevailing drought conditions.

The macroinvertebrate fauna of the upper Snowy River, reference sites and control sites remained distinct throughout the study due to ongoing alterations to flows in the Snowy River. These biological patterns were not consistent with the environmental flows significantly altering Snowy River assemblage composition. The continued reduction in habitat diversity and area, and constancy of hydraulic habitats caused by Jindabyne Dam, despite the small increases in flows, are likely to be the principal mechanisms responsible for the upper Snowy River macroinvertebrate assemblages remaining dissimilar to the reference site assemblages. Total wetted area and riffle area increased by approximately 50% with the environmental flows in the upper Snowy River. It is possible that while macroinvertebrate density, family richness and assemblage composition were not altered greatly by the EFR, total invertebrate abundance in riffle habitats may have increased in relation to increased riffle habitat area. There is unlikely to be a change in the upper Snowy River macroinvertebrate assemblage composition until base flows are increased and high flow events are an integral part of the environmental flow regime.

The macroinvertebrate assemblages within riffle and pool edge habitats of the midland and lowland macro-reaches of the Snowy River did not exhibit any responses that could be related to the environmental flow releases. The macroinvertebrate assemblages of the pool edge habitats within the midland and lowland macro-reaches of the Snowy River exhibited drought related effects. These were declines in densities of most macroinvertebrate families and increased densities of oligochaete worms.

The faunal differences between the midland and lowland Snowy River and reference site assemblages could be attributed to comparatively higher flows in the Snowy River and site-to-site variation rather than the effects of Jindabyne Dam. The provision of further environmental flow releases may make the macroinvertebrate assemblages more dissimilar which is contrary to the current hypotheses. The hypotheses for the midland and lowland macro-reaches of the Snowy River (H_3 & H_4) need to be revised to incorporate the current site class differences, the future hydrological changes and potential increase in biological differences with increases in EFR. The macroinvertebrate fauna of the midland and lowland macro-reaches of the Snowy River are likely to exhibit significant compositional changes related to EFR only after the reinstatement of large spring flows.

Table of Contents

List of Figures

List of Tables

1. Introduction

The Snowy River, prior to flow regulation, flowed unimpeded from near the summit of Mt. Kosciuszko in the south eastern highlands of New South Wales to the southern Australian coast in Victoria (Figure 1). A number of water storages were constructed in the upper river as part of the Snowy Mountains Scheme (SMS) between 1955 and 1967, the largest being Lake Eucumbene and Lake Jindabyne. In addition, flows from the Mowamba River catchment were diverted by aqueduct to Jindabyne Dam. The main purpose for the construction of the SMS was for power generation and to provide water to the Murray River and Murrumbidgee Irrigation Area, and the scheme diverted approximately 96% of mean annual natural flow (MANF) flow from the Snowy River downstream of Jindabyne Dam as measured at Dalgety (Morton & Green 2007).

The construction of the SMS and Jindabyne Dam has affected all components of the flow regime in the upper Snowy River, with a reduction in flow variability, baseflows, large spring snowmelt flows and large floods. The hydrological effects of the construction of the SMS lessen along the course of the river with reductions in MANF of approximately 65% in the lower Snowy River, mainly as a result of lower magnitude, duration and frequency of floods. In October 2000 the Victorian, NSW and Federal Governments agreed to release environmental flows to the Snowy River in stages. The environmental flow allocation was to be 21 % MANF first ten years after the first environmental flows which commenced in 2002. The objective of the environmental flow regime was to improve the environmental condition of the Snowy River below Jindabyne Dam and to restore the ecological and physical components of the river as much as possible to pre-regulation conditions. This was to be achieved by ensuring the water releases mimic daily and seasonal natural flows. The details of the environmental flow releases (EFR) are to be determined by the Snowy Scientific Committee which has not yet been formed, however, in general the EFR is likely to provide an annual large flood event (>20 000Ml/d), increased baseflow volume, more natural daily and seasonal flow variability, and an increased frequency of flushing flows (>1000Ml/d). The first stage of the EFR to the Snowy River began in August 2002 and was provided by decommissioning the Mowamba River aqueduct. This aqueduct had the capacity to divert all flows up to 520ML/d from Mowamba River to Jindabyne Dam and the decommissioning allowed all flows from Mowamba River to enter the Snowy River.

The hydrological and ecological impacts of regulation on riverine ecosystems are widely documented (Petts 1984, Pringle *et al.* 2000, Magilligan & Nislow 2005). Altered flow regimes affect macroinvertebrates and other aquatic fauna by altering physical habitat, interrupting their life history strategies, limiting longitudinal and lateral connectivity and facilitating the invasion and success of introduced species (Bunn & Arthington 2002). A number of studies have demonstrated changes to macroinvertebrate assemblages due to alterations of flow regimes caused by dams (Boon 1988, Armitage & Pardo 1995, Englund & Malvquist 1996, Pringle *et al.* 2000) and the taxa that are affected by river regulation do not appear to be consistent and are difficult to predict. The upper Snowy River has experienced extended periods of low flow conditions and these hydrological impacts have been found in other rivers to result in a depauperate macroinvertebrate assemblage dominated by chironomids (Lake & Marchant 1990, Rader & Belish 1999). High flows, particularly the spring snowmelt flows, have been suggested to be highly influential in determining biological composition (Biggs *et al.* 2005) and the reduction of these flow types in the upper Snowy River is expected to have an important effect on macroinvertebrate assemblage structure. The extent to which the macroinvertebrate assemblages within the Snowy River respond to the first stage of the EFR will be dependent on the degree to which the flows are altered from the current hydrological regime to a more natural regime.

The Snowy River Environmental Flow Response Monitoring Project was established to provide a physical, chemical and biological assessment of the river and quantify the changes, if any, caused by the implementation of EFR. The aquatic macroinvertebrate component of the program began in spring 1999 and the sampling was modified in autumn 2000 to focus on two mesohabitats (riffle, pool edges). The macroinvertebrate monitoring program aims to assess if the macroinvertebrate assemblages in the Snowy River become more similar to those in nearby unimpounded rivers after the EFR compared to a regulated river with no EFR. This report documents the effects on aquatic macroinvertebrate assemblages of the first stage of the EFR to the Snowy River from Mowamba River (beginning 28 August 2002) incorporating data collected from autumn 2000 to autumn 2005.

2. Methods

2.1. Design and field sampling methods

The Snowy River downstream of Jindabyne Dam flows for 352 km through NSW and Victoria to the river's mouth at Marlo and has a catchment area of 13785km^2. The Snowy River was divided into three macro-reaches for analyses based on geographic and hydrological differences. The three macro-reaches are termed upland, midland and lowland and within each one or more sites are sampled for macroinvertebrates (Figure 1, Table 1, Bevitt *et al.* (2006)). Each site comprises two riffle-pool sequences. Additional sites were sampled in other rivers and were used as reference and control sites for the study. The reference and control sites corresponding to each macro-reach are listed in Table 1. Reference sites were chosen from nearby unregulated rivers and represent the ecological condition the Snowy River is expected to become more similar to with the EFR. The control sites were chosen from rivers with hydrological regimes highly altered due to regulation and will not receive environmental flows. Macroinvertebrate assemblages in the Snowy River were compared to the control sites to determine whether any biological changes observed were related to the EFR rather than region-wide influences and to also assist in quantifying the direction of faunal changes. There were no appropriate midland or lowland control sites identified that could be sampled for this project. Potentially the macroinvertebrate fauna of the reference and control sites could differ from their corresponding Snowy River macro-reaches because of factors other than hydrological regime and flow management and may confound or mask the effects of the EFR. The factors that could contribute to differences in macroinvertebrate assemblages between the reference, control and Snowy River sites for each macro-reach were primarily variations in riparian cover and composition and landuse.

All sites were sampled for macroinvertebrates twice per year (autumn and spring). The Snowy River sites (sites 1-8) and midland & upland reference sites (11, 12 & 13) have all been sampled since autumn 2000. Control Site 22 and lowland reference sites (25 & 26) have been sampled since spring 2000 and control Site 23 has been sampled since autumn 2001. 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 edges 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.

2.2. 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.

Table 1. Macro-reach site groupings, reference sites and control sites.

Macro-reach	Test sites	Reference sites	Control sites
Upland	**Site 1** - Snowy River down stream of Mowamba River		
	Site 2 - Snowy River upstream of Sugarloaf	**Site 12.** Mowamba River **Site 13.** Thredbo River	**Site 22.** Eucumbene River upstream of Nimmo Bridge
	Site 3 - Snowy River @ Rockwell		**Site 23.** Eucumbene River near Montana
	Site 4 - Snowy River downstream of Blackburn Creek		
Midland	**Site 5** - Snowy River @ Burnt Hut Crossing	**Site 11.** Delegate River	-
Lowland	**Site 6** - Snowy River @ Willis		-
	Site 7 - Snowy River @ McKillops Bridge	**Site 25.** Cann River **Site 26.** Buchan River	-
	Site 8 - Snowy River @ Wests Track		-

2.3. Data analysis

2.3.1. Hydrology

The nature of alteration to the hydrology of the Snowy River was investigated by determining the magnitude of the changes in daily flows before and with the EFR. This was carried out at three gauging stations in the Snowy River representing the upland (Dalgety, Site 4), midland (Burnt Hut Crossing, Site 5) and lowland (McKillops Bridge, Site 7) macro-reaches. In addition, the measured daily flows in the upland Snowy River were compared to modelled natural daily flows over the study period. A Sacramento rainfall-runoff model was used to calculate natural flows using flow records from 1956-1967 to simulate flows in the Snowy River catchment in the absence of the SMS (Morton & Green 2007).

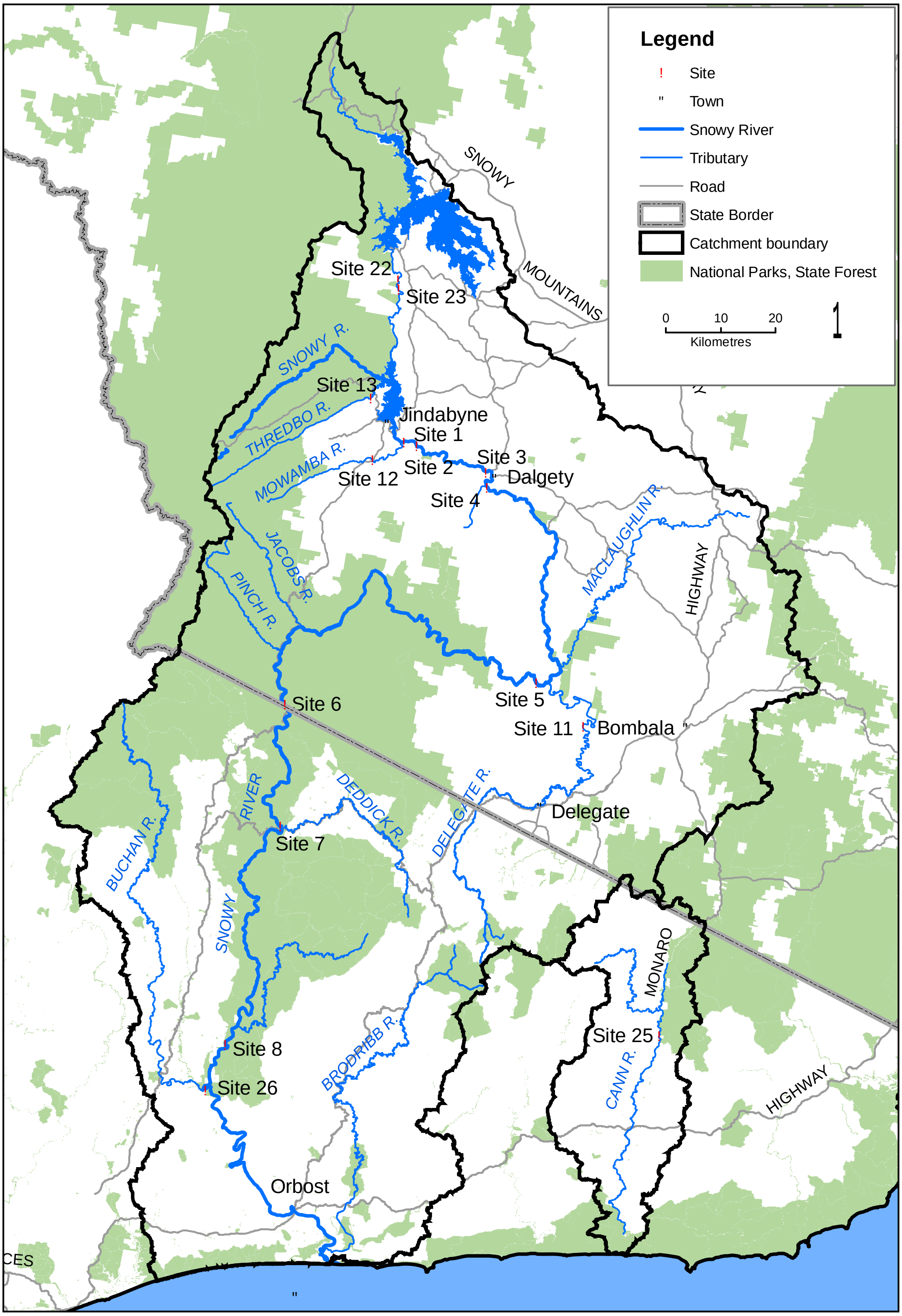


Figure 1. Location of macroinvertebrate reference, control and Snowy River sampling sites.

2.3.2. Macroinvertebrates

At each site and within each habitat, the macroinvertebrate data from the 6 subsamples were averaged prior to statistical analyses.

Three response variables were calculated for each Snowy River site in the study. These were:

- the mean of the differences in family richness per subsample between each of the relevant reference sites and the Snowy River site;
- mean of the difference in density per subsample between the relevant reference sites and the Snowy River site;
- mean Bray-Curtis similarity between relevant reference sites and each Snowy River site.

For each Snowy River site located in the upland macro-reach, an additional three response variables were calculated which included data collected from control sites:

- the mean of the differences in family richness between each of the control sites and the Snowy River site;
- mean of the difference in density between the control sites and the Snowy River site;
- mean Bray-Curtis similarity between control sites and each Snowy River site.

The density based response variables were $\log_{10}$ transformed to ensure data normality and homogeneity of variances. For the calculation of the Bray-Curtis similarity measure, densities of all families were 4^{th} root transformed to reduce differences in scale among variables, but still retain information regarding relative abundances.

These response variables were used to test the following hypotheses:

H_1 The macroinvertebrate assemblage composition within the riffles and pool edges of the Snowy River upland macro-reach (Sites 1, 2, 3 & 4) will become more similar to the macroinvertebrate assemblages of reference sites (Site 12 & 13) after the commencement of the environmental flow regime.

H_2 The macroinvertebrate assemblage composition within the riffles and pool edges of the Snowy River upland macro-reach (Sites 1, 2, 3 & 4) will become less similar to the macroinvertebrate assemblages of control sites (Sites 22 & 23) after the commencement of the environmental flow regime.

H_3 The macroinvertebrate assemblage composition within the riffles and pool edges of the Snowy River midland macro-reach (Site 5) will become more similar to the macroinvertebrate assemblage of the reference site (Site 11) after the commencement of the environmental flow regime.

H_4 The macroinvertebrate assemblage composition within the riffles and pool edges of the Snowy River lowland macro-reach (Sites 6, 7 & 8) will become more similar to the macroinvertebrate assemblages of reference sites (Sites 25 & 26) after the commencement of the environmental flow regime.

The hypotheses relating to the upland Snowy River macro-reach (H_1 & H_2) and lowland Snowy River macro-reach (H_4) were tested using a one factor repeated-measures analysis of variance. For the analyses of response variables relating to H_1, there were four replicates (sites 1, 2, 3 & 4) and eleven treatments (five pre-EFR and six with-EFR sampling occasions). For the analyses of response variables testing H_2, there were four replicates (sites 1, 2, 3 & 4) and ten treatments (four pre-EFR and six with-EFR sampling occasions) as control sites were not sampled until autumn 2000. There were three replicates (sites 6, 7 & 8) and ten treatments (four pre-EFR and 6 with-EFR sampling occasions) for the analysis of response variables testing H_4. Sites represent the 'subjects' and the sampling occasions were the repeated measures made on each 'subject'. Linear and curvilinear trends through time were tested for all response variables. The curvilinear trend tested was no trend before EFR and a logarithmic trend through time with the EFR. This type of trend tests for lagged responses in the dependent variables after the introduction of the EFR. The effect of the EFR could be reflected in both positive and negative trends in the density and family richness variables, depending on the whether the variables were predominately greater than or less than zero prior to the EFR. In both situations the trends should be towards zero if the reference and Snowy River macroinvertebrates become more similar under the EFR (ie. no difference between reference and Snowy River sites), and away from zero if the macroinvertebrates of the control and Snowy River sites become more dissimilar under the EFR. Only positive linear and curvilinear trends in Bray-Curtis similarity were anticipated for H_1 and H_4 (reference-Snowy River comparisons) as the response variable will approach one 100% if the EFR causes the macroinvertebrate assemblages to become more similar. In contrast, only negative linear and curvilinear trends in Bray-Curtis similarity would be expected for H_2 (control-upland Snowy River comparisons) as the response variable will approach zero if macroinvertebrate assemblages become more dissimilar with the EFR.

Samples were not collected from Site 8 in autumn 2002 and autumn 2003. These missing observations were replaced for the above analyses using the method recommended by Quinn and Keough (2002) in Chapter 10.

H_3 was tested using least squares regression to determine if the macroinvertebrate response variables showed a significant linear ($y= \beta_0 + \beta_1.x$) or logarithmic ($y= \beta_0 + \beta_1.\log_{10}x$) relationship through time which was consistent with a response attributable to the EFR. Regression models with and without an autoregressive component (autoregressive process of order 1) were compared using the likelihood ratio test to determine whether serial autocorrelation occurred and needed to be accounted for in the regression model. A regression model was used because there was only a single reference-Snowy River comparison for each response variable and no replication at each sampling occasion making repeated measures analysis inappropriate.

Canonical analysis of principal coordinates (CAP, Anderson & Willis 2003), a constrained ordination technique, was also undertaken to visualise the macroinvertebrate assemblage patterns related to all hypotheses. The Similarity Percentages procedure (SIMPER) was used to identify the taxa responsible for spatial and temporal patterns, if any, observed in the CAP ordination (Clarke 1993).

2.4. Changes to hydraulic conditions within Snowy River Site 4 with the provision of the EFR

The average changes to hydraulic conditions at Snowy River Site 4 after the commencement of EFR were assessed by comparing the total wetted habitat area and total riffle area at the median daily flow prior to EFR and median daily flows with the EFR. Riffle was defined as areas within the site where Froude number exceeded 0.2 (Jowett 1993). The differences in the hydraulic characteristics were determined by developing a 1 dimensional hydraulic model for the two daily flows (see Reinfelds *et al.* 2004).

A total of 840 spot heights covering 53 560m^2 of the riverbed were surveyed throughout the pools and riffles within Site 4, and recorded as X, Y, Z co-ordinates using a total station. The topographic survey data were used to construct triangulated irregular network (TIN) or finite element mesh models of the site using standard procedures in Arcview 3D Analyst 1.0 (ESRI, 1999). Standard procedures described in Ackerman (2002) for the Arcview HEC-GeoRAS 1.0 extension were used to develop import and export files from the TIN models to facilitate both development of hydraulic models in HEC-RAS 3.0 and post-processing of the final modelling results within Arcview 3.2. The optimal model calibration occurred with Manning's 'n' values set to 0.05.

3. Results

3.1. Hydrology, hydraulics and environmental flow releases

3.1.1. Hydrology and environmental flow releases

The decommissioning of Mowamba River aqueduct caused ongoing increases to flows entering the Snowy River from Mowamba River throughout the period of the study. The median daily flows increased in the upland macro-reach (as measured at Dalgety) from 42.5 Mld^{-1} to 78.6 Mld^{-1} with the environmental flow releases from Mowamba Weir and flows at the corresponding reference site (Site 13 Thredbo River) declined slightly from 275 Mld^{-1} to 248 Mld^{-1} (Figure 1a). The median daily flows in the midland and lowland Snowy River macro-reaches both declined over the same period (290 to 175ML/d for midland, 722 to 441 ML/d for lowland, Figure 1b & c). Discharge in the midland and lowland reference rivers were lower than flows in the Snowy River and also reduced during the period with EFR (175 to 103 Mld^{-1} for midland, 176 to 119 Mld^{-1} for lowland, Figure 1b & c).

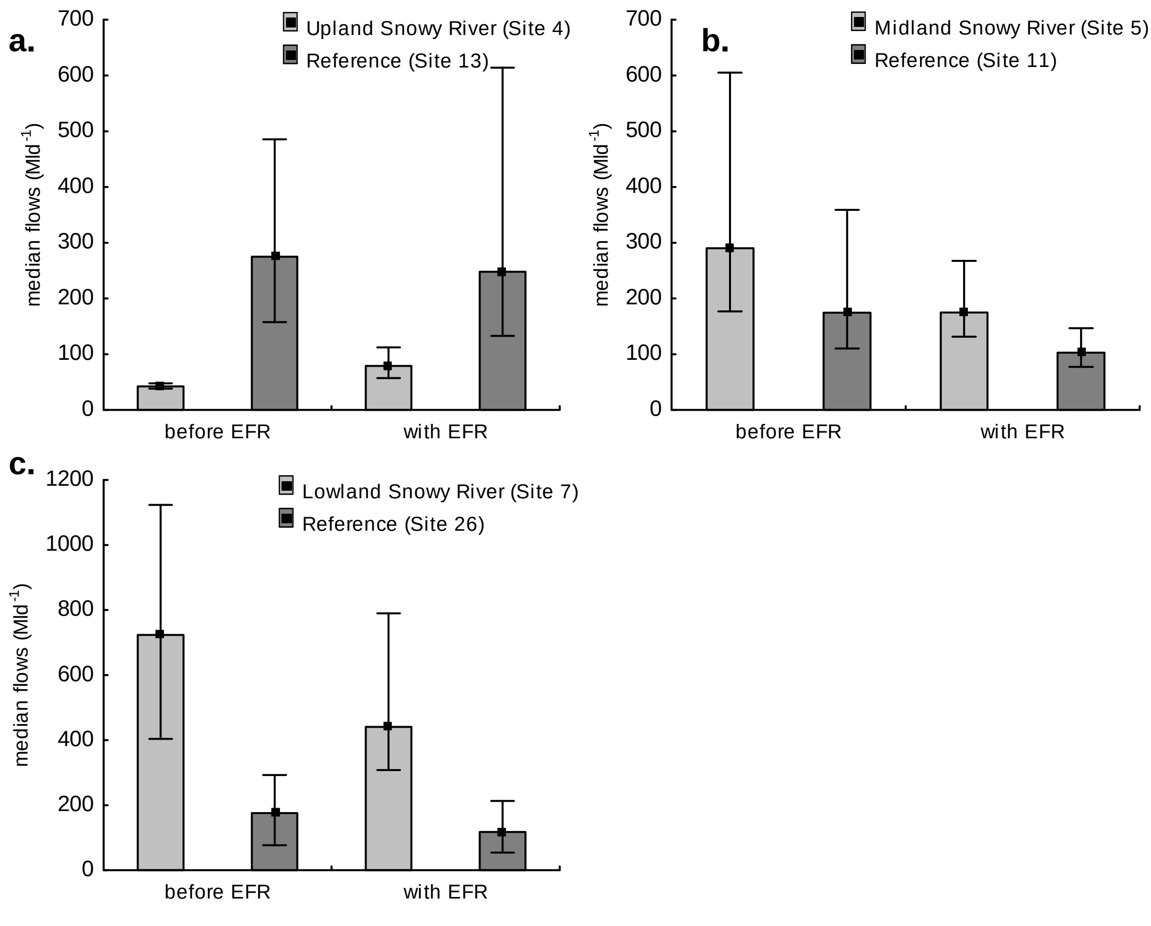


Figure 2. Median daily flows in a) upland, b) midland and c) lowland Snowy River before and with EFR (error bars are 25th%-75th%).

The daily flows in the upland Snowy River after provision of environmental flows were significantly lower than the simulated natural flows (1181 Mld^{-1}) for the period (Figures 3a & 3b). However there was an increase in daily variability and a pattern of seasonality (higher spring flows) that occurred with EFR (Figure 3b). The median daily reference river flows (248 Mld^{-1}) were approximately 3 times higher than the upland Snowy River with EFR (Figure 1a) and were much more variable and exhibited clear seasonal patterns (Figure 3a & b). The high flows (90th % flows) in the Snowy River during the period with EFR were 172.5 Mld^{-1} compared with 5461.6 Mld^{-1} for simulated natural Snowy River flows and 965 Mld^{-1} for reference river flows.

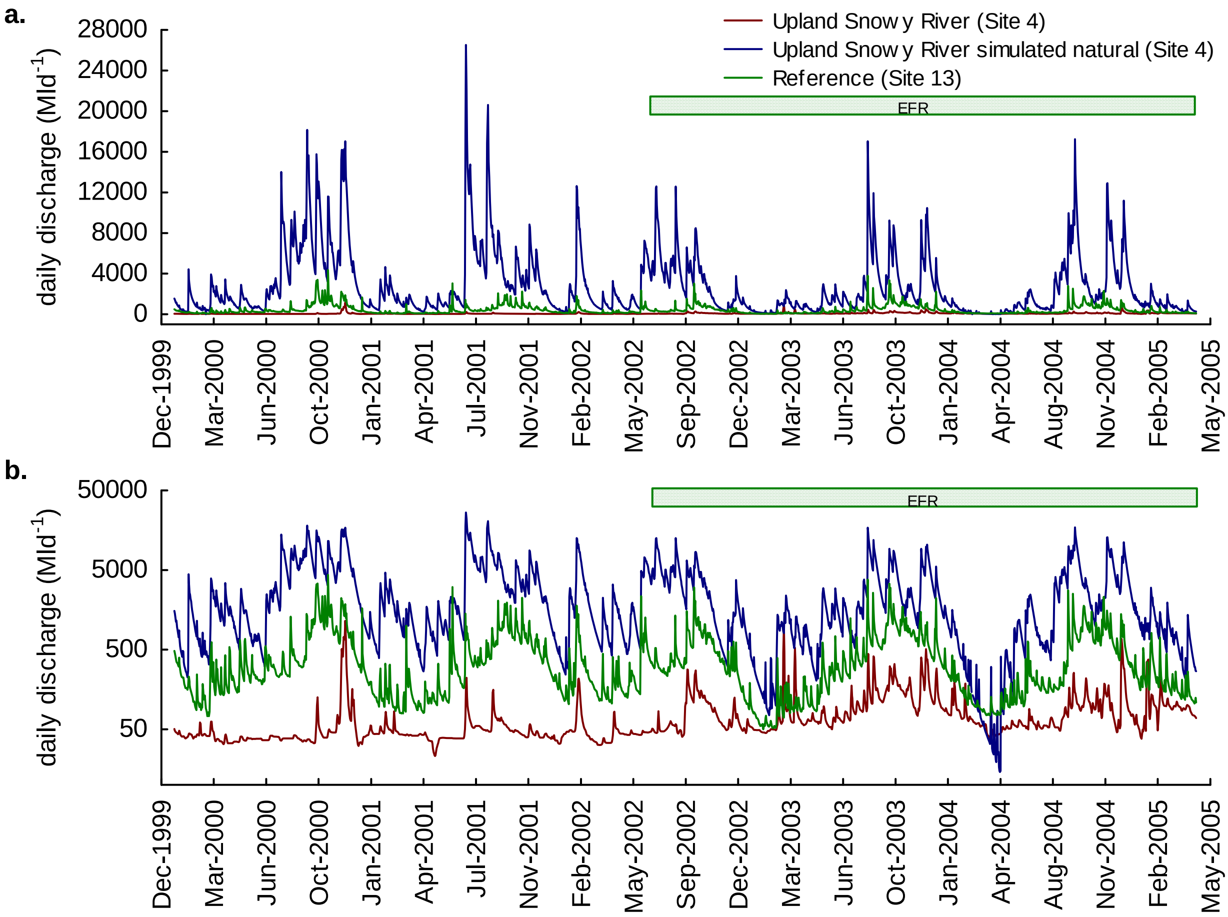


Figure 3. Reference river daily flows compared with upland Snowy River daily flows and simulated natural daily flows from December 1999 to April 2005. a) linear scale and b) logarithmic scale.

The daily flows in the midland and lowland Snowy River were much higher than flows at the reference sites and much more variable throughout the study period (Figure 4). There was a decline in daily discharge after the EFR began in the midland and lowland reference sites which corresponded to similar reductions in the Snowy River. There was also a decline in the frequency of high flows in the midland and lowland Snowy River macro-reaches during the period of the EFR. The declines in both reference sites and Snowy River sites reflect the drought conditions that persisted throughout the region during 2002-2005.

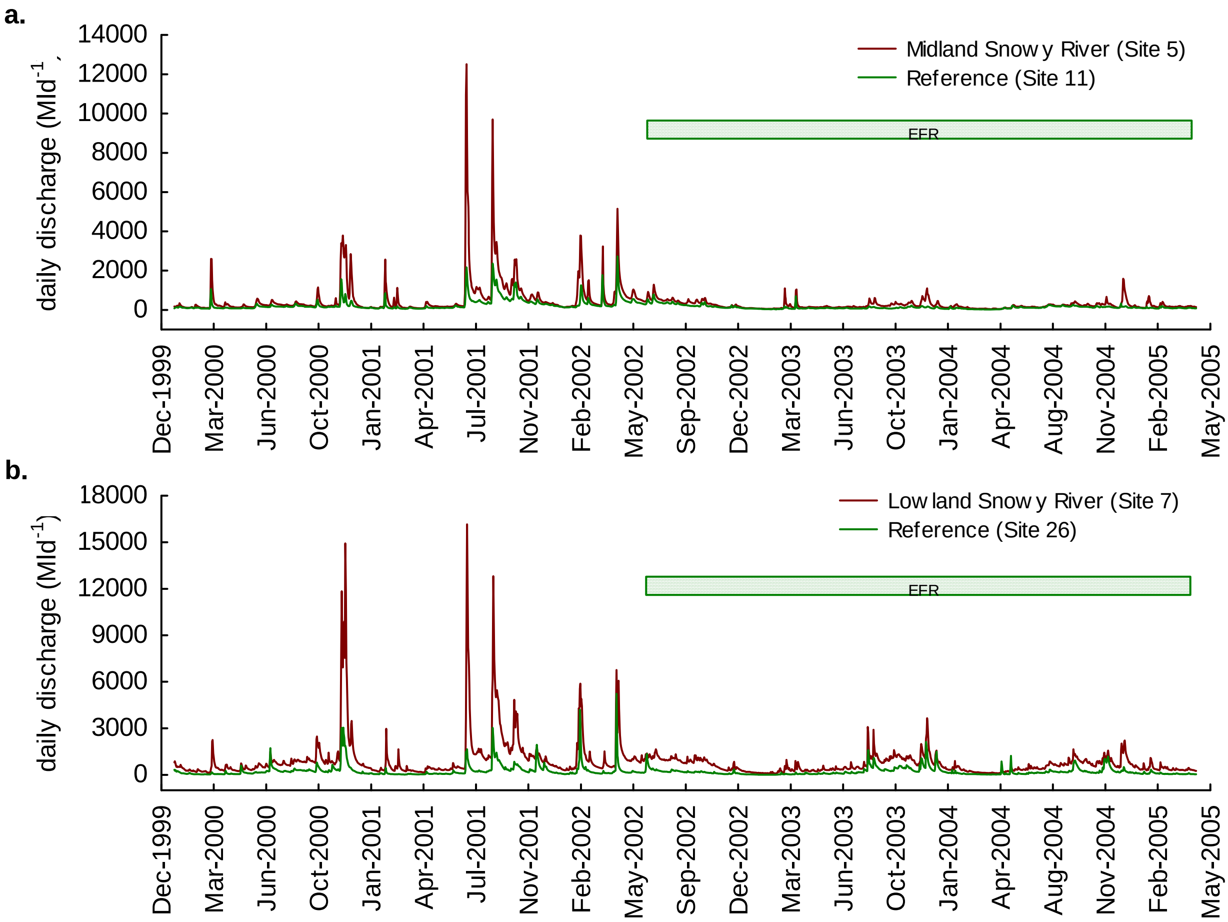


Figure 4. Daily flows in reference and Snowy River sites a) midland and b) lowland Snowy River macro-reaches from December 1999 to April 2005

3.1.2. Hydraulic changes within the Snowy River at Dalgety (Site 4)

The median daily flows modelled were 40Ml/d and 80Ml/d which were approximately the median daily flows before EFR and with EFR over the study period. The total wetted area for the site increased by approximately 50% (8076m^2 to 12391m^2) and the average depth increased by approximately 10cm in pools and 5cm in riffles (Figure 5). The total area of riffle increased from 405.0m^2 to 628.5m^2 (Figure 5).

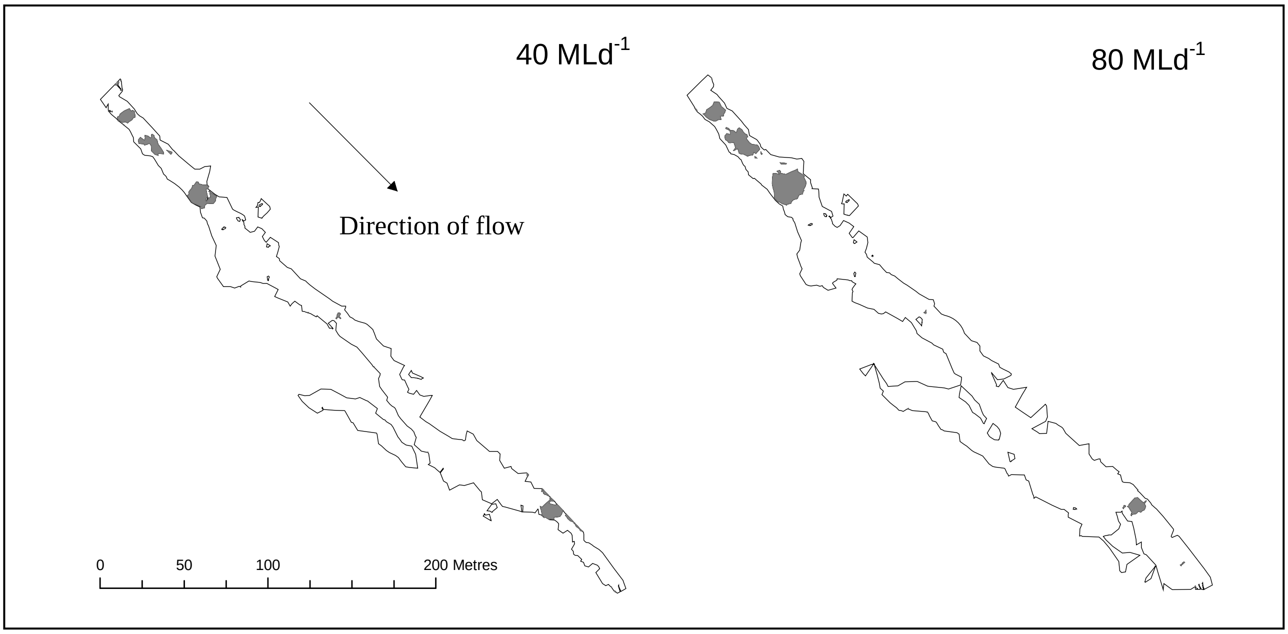


Figure 5. HEC-GeoRAS hydraulic model of Site 4 (Snowy River at Dalgety) showing wetted area and riffle area at river flows of 40ML/d and 80 ML/d. Grey shading indicates riffle area and white indicates total wetted area.

3.2. Upland Snowy River macro-reach - macroinvertebrate response to EFR

3.2.1. Riffles

A total of 77 invertebrate families were found in the 8 sites from 11 sampling occasions. The densities of samples ranged from 10 to 1420 individuals per $0.07m^2$. The control sites contained higher levels of family richness per subsample over the study period than both the reference and Snowy River sites (Figure 6). The densities of macroinvertebrates within the Snowy River, reference and control sites were similar throughout the study (Figure 7).

The repeated measures ANOVA indicated that there were no significant trends in differences in macroinvertebrate density, differences in family richness or assemblage composition between Snowy River and reference sites through time (Table 2, Figures 6, 7 & 8). Therefore, hypothesis H_1 was not supported by the results.

Table 2. Summary of repeated measures ANOVA results for riffles comparing the macroinvertebrate assemblage similarity, difference in family richness and difference in density (log_{10}) between the upland Snowy River and reference sites.

		Reference – Snowy River Bray-Curtis assemblage similarity		Reference – Snowy River difference in family richnesss		Reference – Snowy River difference in density (log_{10})	
Source of variation	**d.f.**	**MS**	**F**	**MS**	**F**	**MS**	**F**
Linear trend	1	38.77	1.94	16.42	1.13	<0.01	0.0130
Error	3	19.93		14.58		0.06	
Curvilinear trend	1	184.85	7.04	10.77	0.85	<0.01	0.25
Error	3	26.25		12.66		0.03	

***P<0.05, ** P<0.01**

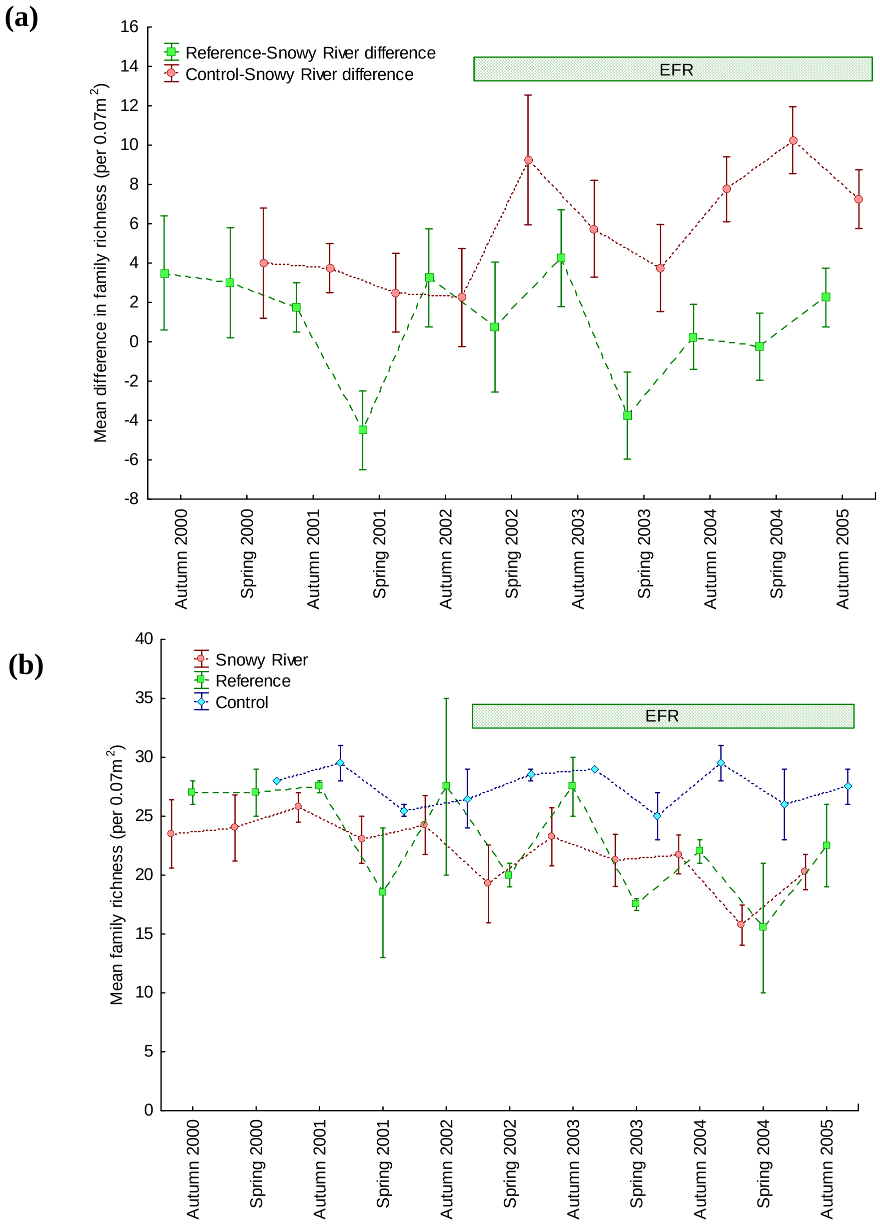


Figure 6. Macroinvertebrate family richness in upland riffles before and with EFR. a) mean family richness in Snowy River, control and reference sites, and b) mean difference in family richness between reference and Snowy River sites and between control and Snowy River sites (error bars ± 1 S.E.).

There were significant positive linear trends for differences in macroinvertebrate density, differences in family richness and assemblage structure between Snowy River and control sites through time (Table 3, Figures 6, 7, & 8). There were significant positive curvilinear trends for differences in macroinvertebrate density and family richness and a near significant trend in assemblage composition between Snowy River and control sites through time. Macroinvertebrate density in the Snowy River appeared to decline at a faster rate than density in the control sites (Figure 7) and family richness remained stable within the control sites but decreased within the Snowy River through time (Figure 6). The patterns in the response variables over the study period were not consistent with accepting hypothesis H_2. In particular, the increasing similarity of the assemblage composition of the Snowy River and control sites through time does not imply that the EFR had any effect on macroinvertebrates.

Table 3. Summary of repeated measures ANOVA results for riffles comparing the macroinvertebrate assemblage similarity, difference in family richness and difference in density (log_{10}) between the upland Snowy River and control sites.

		Control – Snowy River Bray-Curtis assemblage similarity		Control – Snowy River difference in family richnesss		Control – Snowy River difference in density (log_{10})	
Source of variation	**d.f.**	**MS**	**F**	**MS**	**F**	**MS**	**F**
Linear trend	1	10.36	**10.36***	126.11	**18.47***	0.39	**11.46***
Error	3	38.25		6.83		<0.03	
Curvilinear trend	1	391.51	9.83 (p=0.052)	146.13	**19.83***	0.30	**19.54***
Error	3	39.81		7.37		<0.02	

***P<0.05, ** P<0.01**

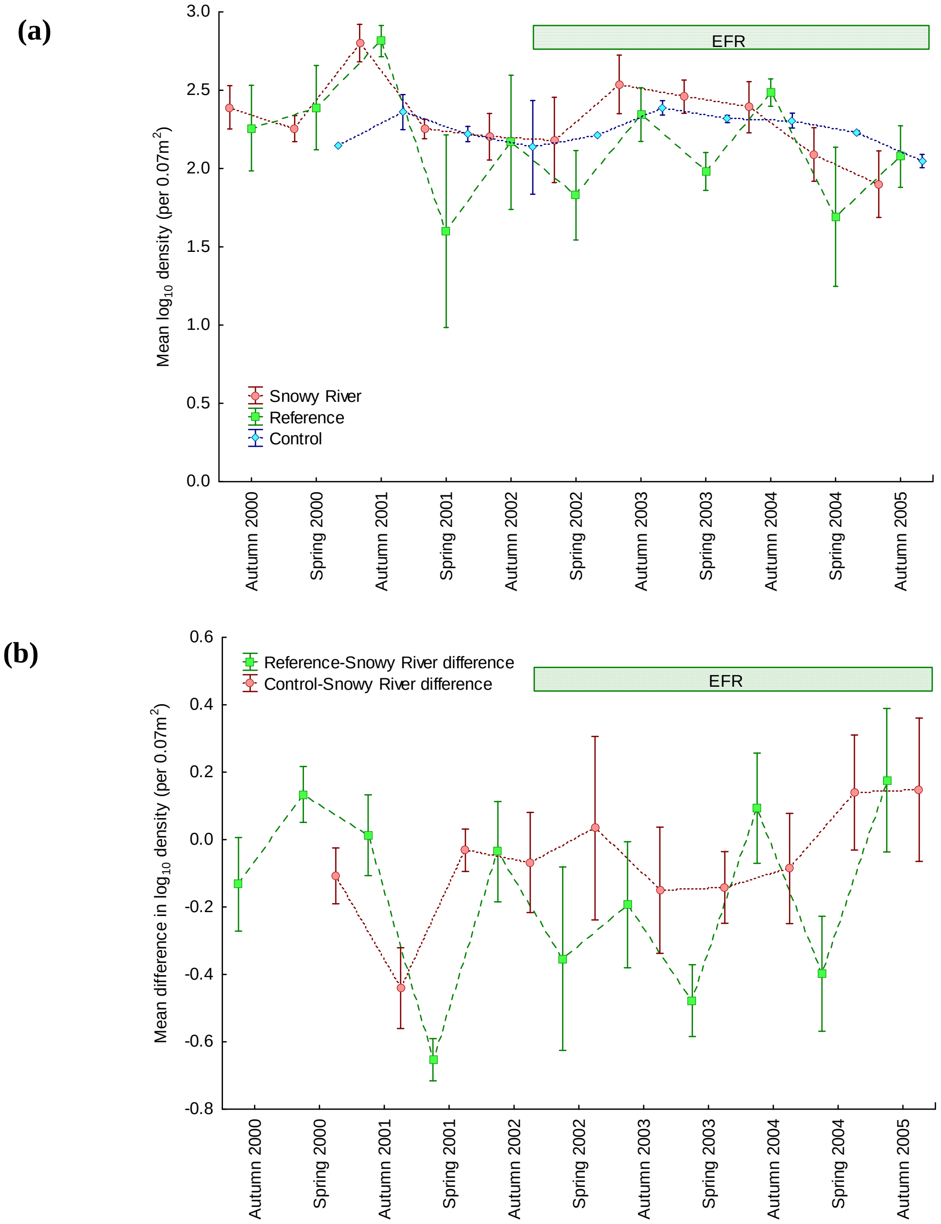
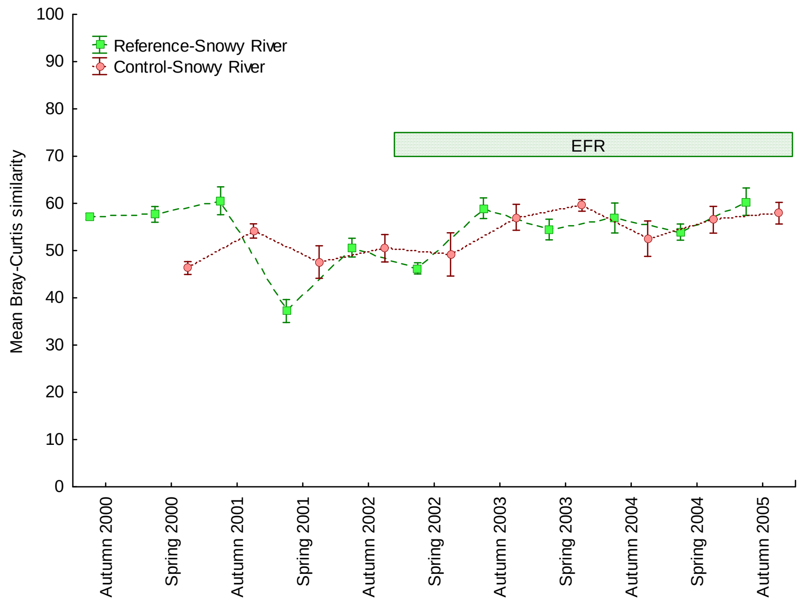


Figure 7. Macroinvertebrate log_{10} density in upland riffles before and with EFR. a) mean density in Snowy River, control and reference sites, and b) mean difference in density between reference and Snowy River sites and between control and Snowy River sites (error bars ± 1 S.E.).

The three site classes (reference, Snowy River, control) had very different macroinvertebrate assemblage compositions throughout the study period (Figure 8a & 8b). The taxa that distinguished the different site classes are shown in Figure 9. In general, the reference sites contained higher densities of caddisflies (Conoesucidae and Hydropsychidae) and Elmidae (larvae and adult), Snowy River sites typically had higher densities of caenid mayflies and Chironomidae, and the control sites contained higher densities of leptophlebiid mayflies and isopods (Phreatoicidae) (SIMPER, Appendix Table A1). The slight increase in assemblage similarity between the Snowy River sites and control sites was attributable to declines in the densities of caenid mayflies, Hydroptilidae and Hydropsychidae and increases in densities of oligochaete worms, Simuliidae and Chironomidae in the Snowy River in the latter sampling periods.

(a)



(b)

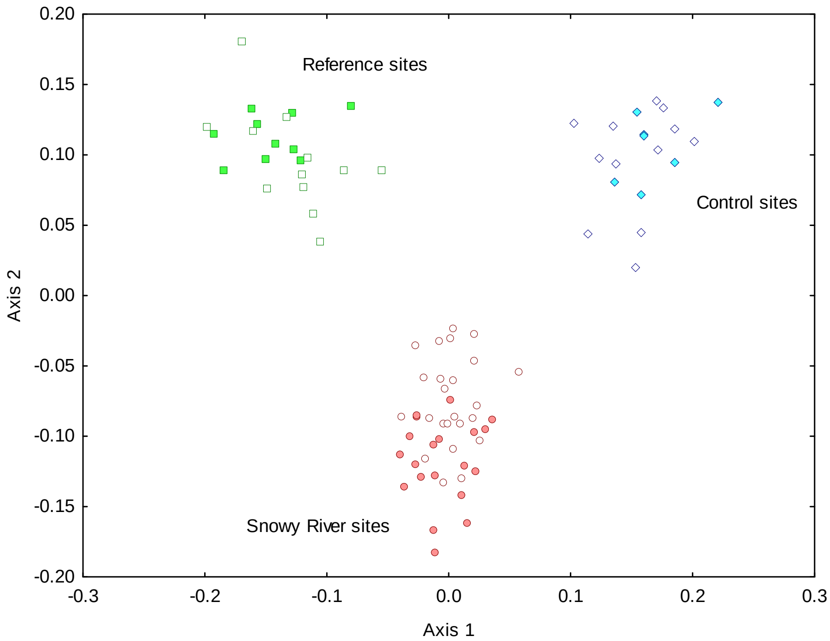


Figure 8. Macroinvertebrate assemblage similarity in upland riffles (Bray-Curtis similarity) before and with EFR. a) mean assemblage similarity between reference and Snowy River sites and between control and Snowy River sites (error bars ± 1 S.E.), and b) canonical analysis of principal components (CAP) ordination on macroinvertebrate assemblages in Snowy River, control and reference sites, and before (closed symbols) and with EFR (open symbols).

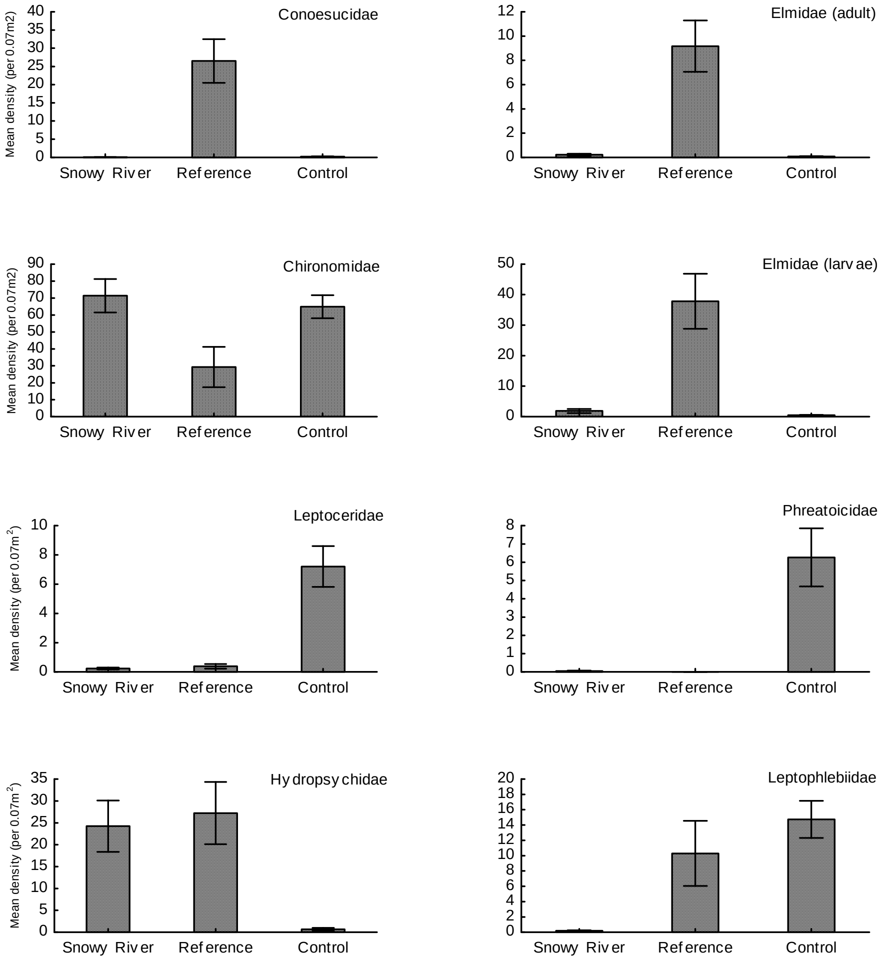


Figure 9. Mean density of macroinvertebrate families from riffles contributing most to differences between upland Snowy River, control and reference sites (error bars ± 1 S.E.).

3.2.2. Pool edges

A total of 83 invertebrate families were found in the 8 sites from the 11 sampling occasions. The densities of samples ranged from 55 to 1279 individuals per $0.07m^2$. In general, the control sites contained higher levels of family richness per subsample over the study period than both the reference and Snowy River sites (Figure 10). The densities of macroinvertebrates within the reference and control sites were similar and consistently lower than those recorded within the Snowy River (Figure 11).

The repeated measures ANOVA indicated that there were no significant trends in differences in macroinvertebrate density, differences in family richness or assemblage structure between Snowy River and reference sites through time (Table 4, Figures 10, 11 & 12). Therefore, hypothesis H_1 was not supported by these results.

There were no significant trends in differences in macroinvertebrate density or differences in family richness between Snowy River and control sites through time and H_2 was unsupported (Table 5, Figures 10 & 11). In general, family richness and density declined at all site classes through time and therefore the magnitude of the differences did not show any significant pattern over the period of study.

Table 4. Summary of repeated measures ANOVA results for pool edges comparing the macroinvertebrate assemblage similarity, difference in family richness and difference in density (log_{10}) between the upland Snowy River and reference sites.

		Reference – Snowy River Bray-Curtis assemblage similarity		Reference – Snowy River difference in family richnesss		Reference – Snowy River difference in density (log_{10})	
Source of variation	**d.f.**	**MS**	**F**	**MS**	**F**	**MS**	**F**
Linear trend	1	39.62	0.89	11.14	1.66	0.0712	3.1543
Error	3	44.34		6.70		0.0226	
Curvilinear trend	1	41.87	0.76	25.69	2.02	0.1007	4.6923
Error	3	54.76		12.74		0.0215	

***P<0.05, ** P<0.01**

Table 5. Summary of repeated measures ANOVA results for pool edges comparing the macroinvertebrate assemblage similarity, difference in family richness and difference in density (log_{10}) between the upland Snowy River and control sites.

		Control – Snowy River Bray-Curtis similarity		Control – Snowy River difference in family richnesss		Control – Snowy River difference in density (log_{10})	
Source of variation	**d.f.**	**MS**	**F**	**MS**	**F**	**MS**	**F**
Linear trend	1	72.46	**18.80***	16.59	1.33	<0.001	<0.001
Error	3	3.85		12.49		0.0209	
Curvilinear trend	1	100.63	**30.62***	16.05	0.94	0.005	0.0200
Error	3	3.29		16.99		0.0263	

***P<0.05, ** P<0.01**

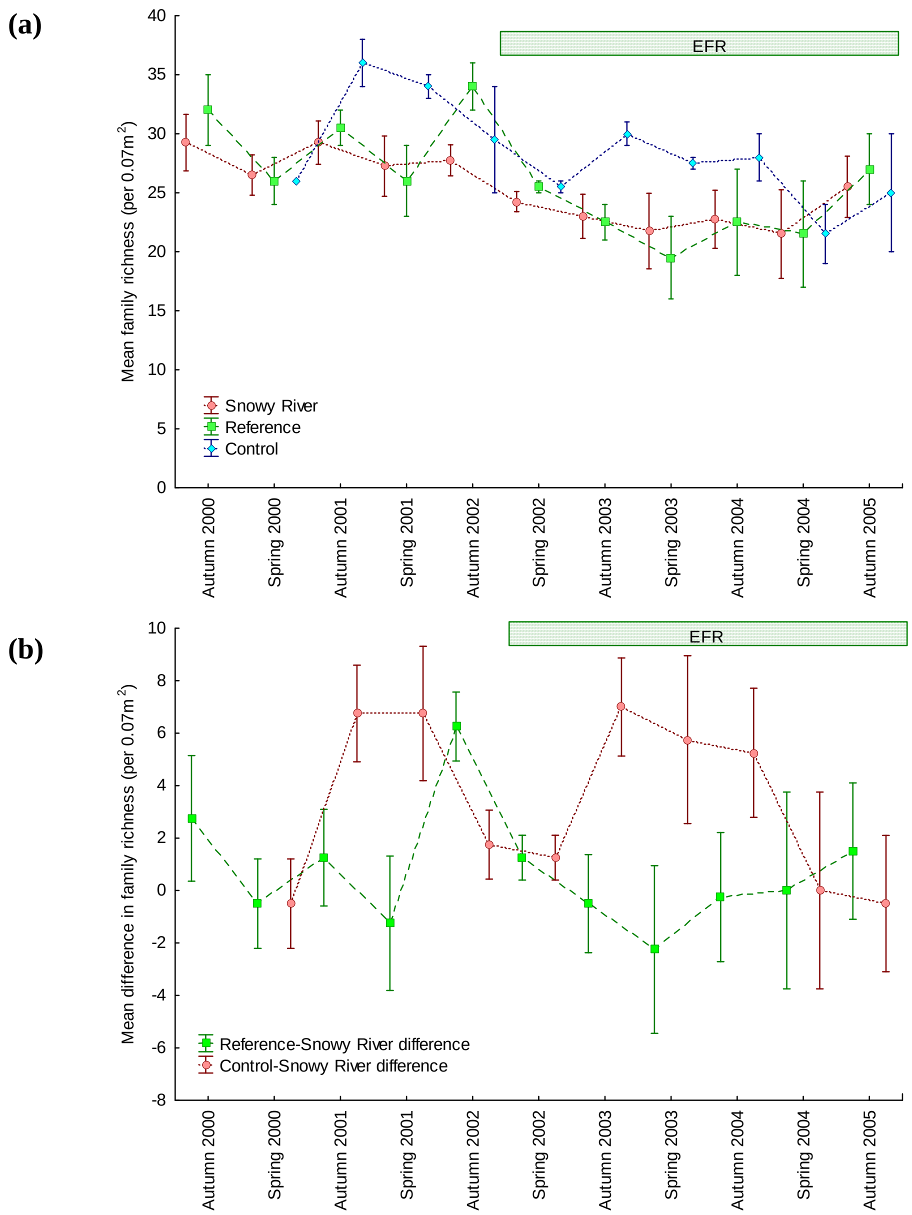


Figure 10. Macroinvertebrate family richness in upland pool edges before and with EFR. a) mean family richness in Snowy River, control and reference sites, and b) mean difference in family richness between reference and Snowy River sites and between control and Snowy River sites (error bars ± 1 S.E.).

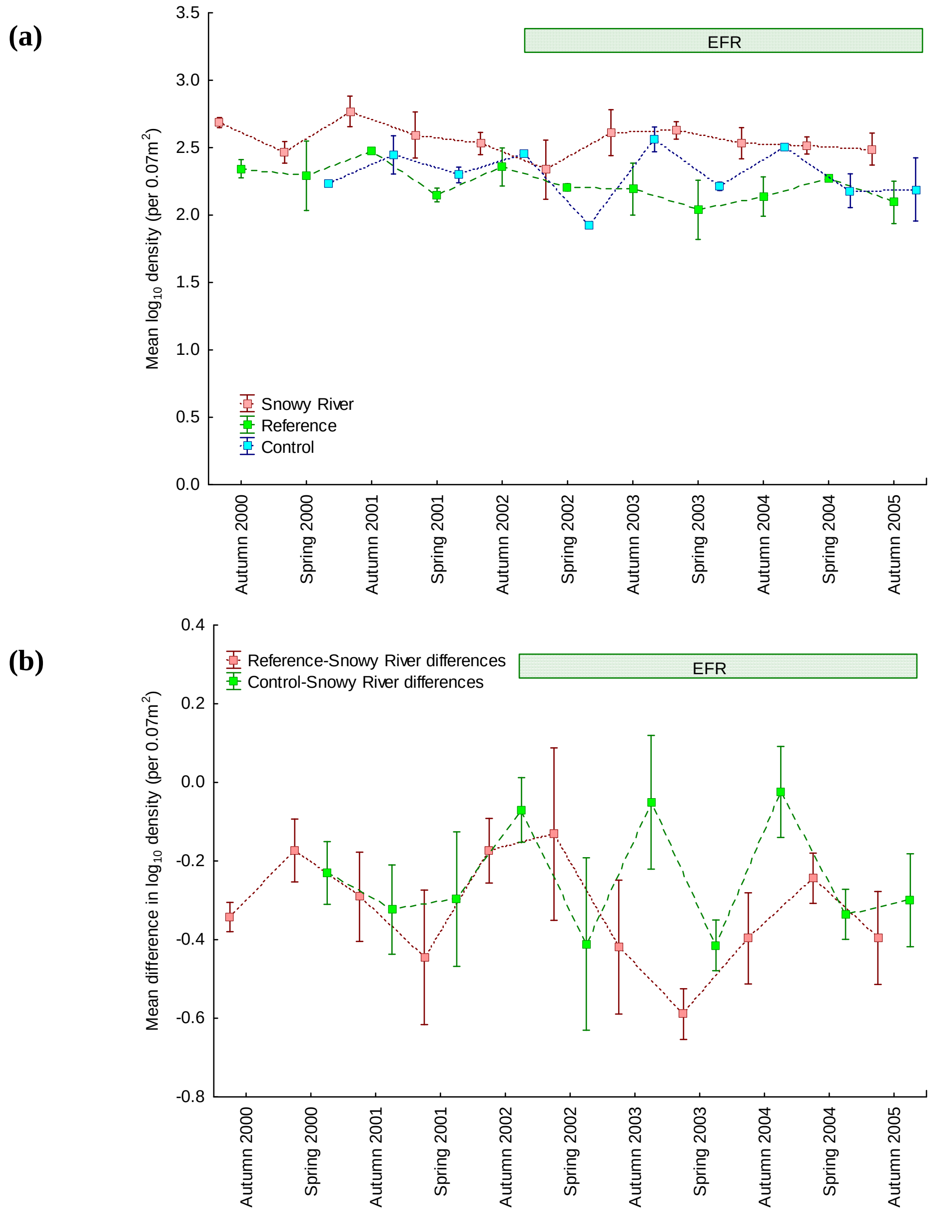
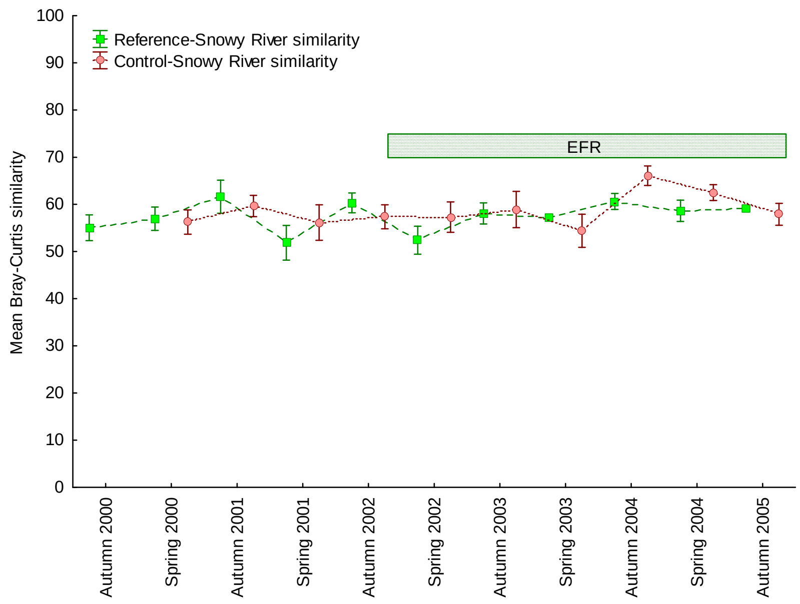


Figure 11. Macroinvertebrate log_{10} density in upland pool edges before and with EFR. a) mean density in Snowy River, control and reference sites, and b) mean difference in density between reference and Snowy River sites and between control and Snowy River sites (error bars ± 1 S.E.).

There were significant positive linear and curvilinear trends in Bray Curtis similarity between the Snowy River sites and control sites through time (Table 5, Figure 12). These trends do not appear to be large and are likely to result from the slightly higher assemblage similarity between control sites and Snowy River sites in autumn 2004. There were distinct differences in assemblage structure between the reference, control and Snowy River sites throughout the study (Figure 12). The taxa that distinguished the different site classes are shown in Figure 13. In general, the reference sites contained higher densities of Oniscigastridae, Snowy River sites typically had higher densities of Oligochaeta, and the Control sites contained higher densities of Lestidae, leptophlebiid mayflies, amphipods (Ceinidae), isopods (Phreatoicidae), Leptoceridae and Odontoceridae (SIMPER - Appendix Table A2).

(a)



(b)

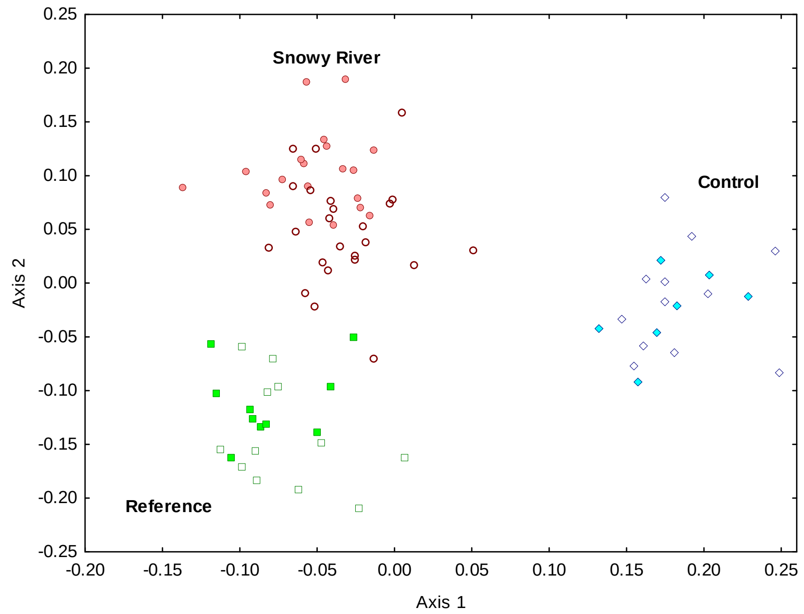


Figure 12. Macroinvertebrate assemblage similarity in upland pool edges (Bray-Curtis similarity) before and with EFR. a) mean assemblage similarity between reference and Snowy River sites and between control and Snowy River sites (error bars ± 1 S.E.), and b) canonical analysis of principal components (CAP) ordination on macroinvertebrate assemblages in Snowy River, control and reference sites, and before (closed symbols) and with EFR (open symbols).

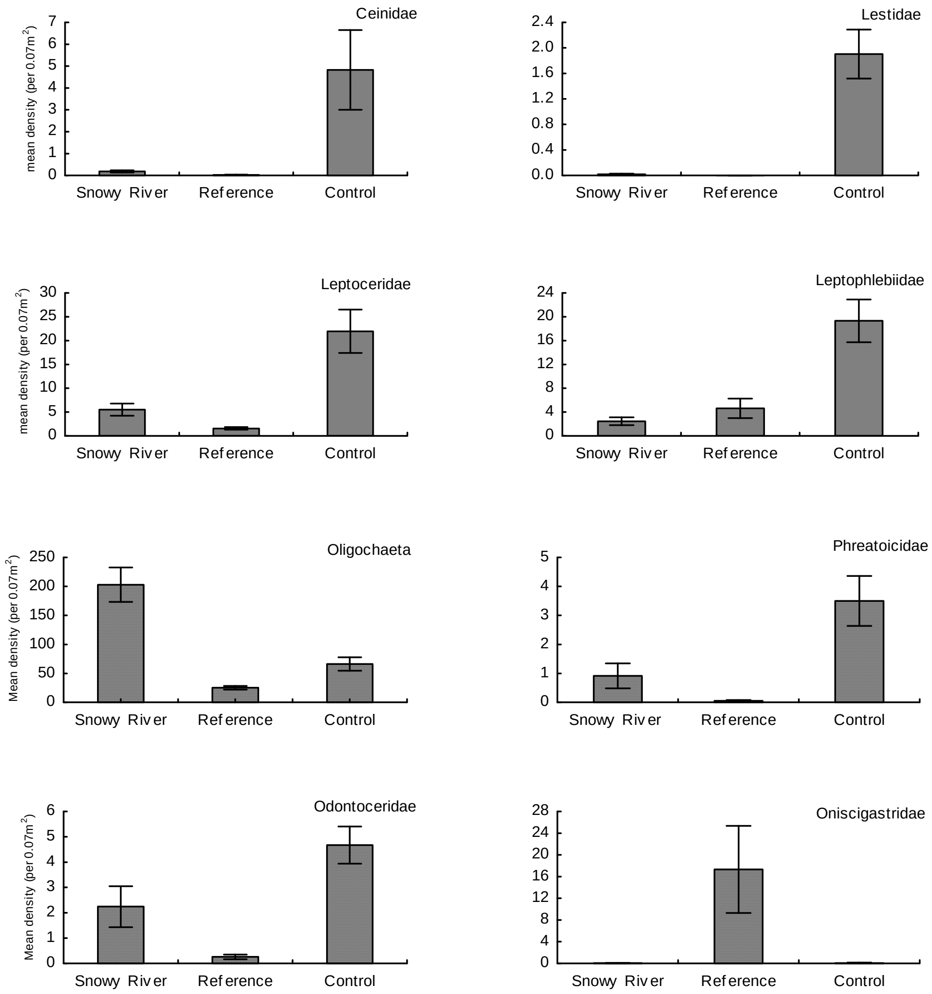


Figure 13. Mean density of macroinvertebrate families from pool edges contributing most to differences between upland Snowy River, control and reference sites (error bars ± 1 S.E.).

3.3. Midland Snowy River macro-reach - macroinvertebrate response to EFR

3.3.1. Riffles

A total of 50 invertebrate families were collected from the 2 midland sites from the 11 sampling occasions. The densities of samples ranged from 70-433 individuals per $0.07m^2$.

There was no evidence of serial correlation in any of the response variables and least squares regression with no autocorrelation component was used to test the hypotheses. There were no significant linear or logarithmic trends in assemblage similarity, differences in family richness or differences in density between Snowy River and reference sites throughout the study (Table 6, Figures 14, 15 & 16). Macroinvertebrate family richness and density did not appear to differ between the reference and Snowy River site. This was evident in the family richness and density differences varying about zero over the study period. These results were not consistent with the responses described in H_3.

Table 6. Summary of linear and logarithmic least squares regression results for macroinvertebrate assemblage similarity, difference in family richness and difference in density (log_{10}) from riffles in the midland Snowy River and reference sites through time.

		Reference – Snowy River Bray-Curtis similarity	**Reference – Snowy River difference in family richnesss**	**Reference – Snowy River difference in density (log_{10})**
Trend	**d.f.**	**β_0 t value**	**β_0 t value**	**β_0 t value**
linear	1, 9	1.25	0.23	0.59
logarithmic	1,9	0.58	0.34	0.53

***P<0.05, ** P<0.01**

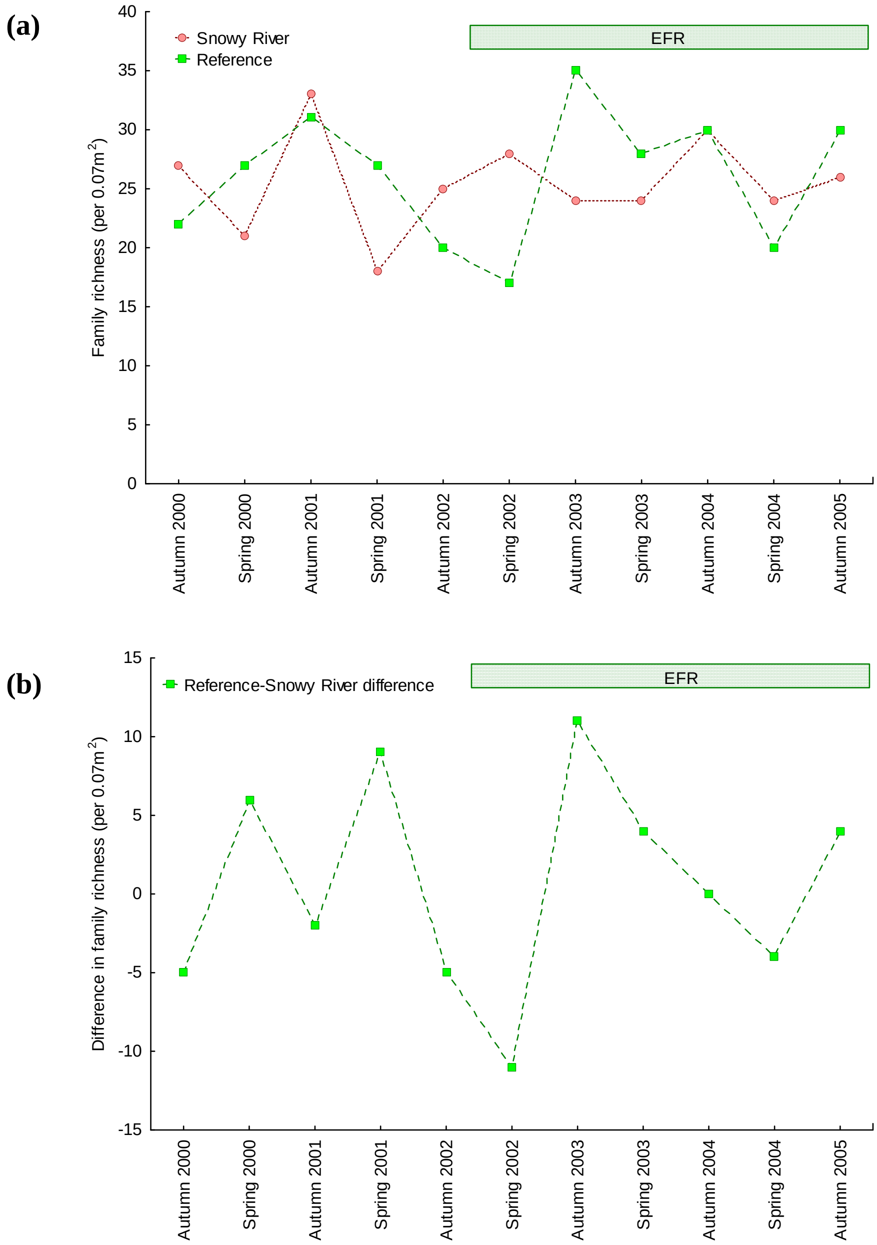
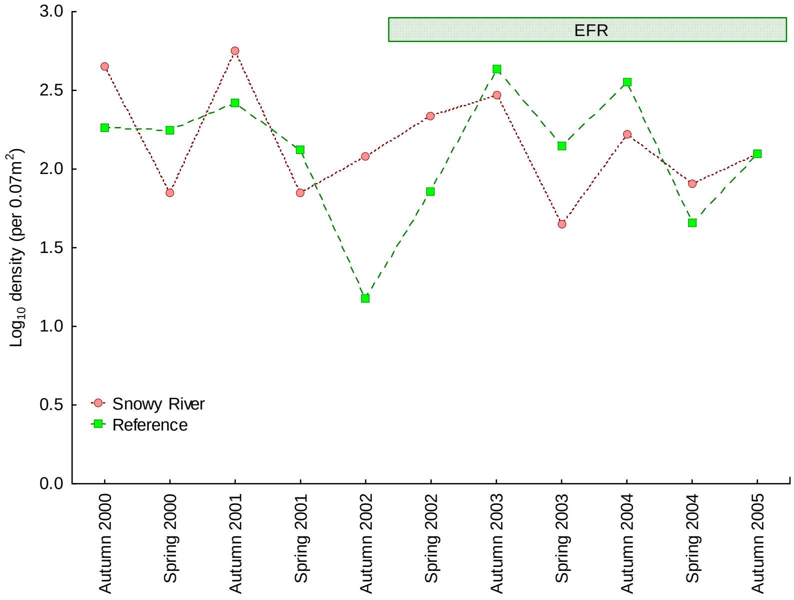


Figure 14. Macroinvertebrate family richness in midland riffles before and with EFR. a) family richness in Snowy River and reference sites. b) differences in family richness between reference and Snowy River sites.

(a)



(b)

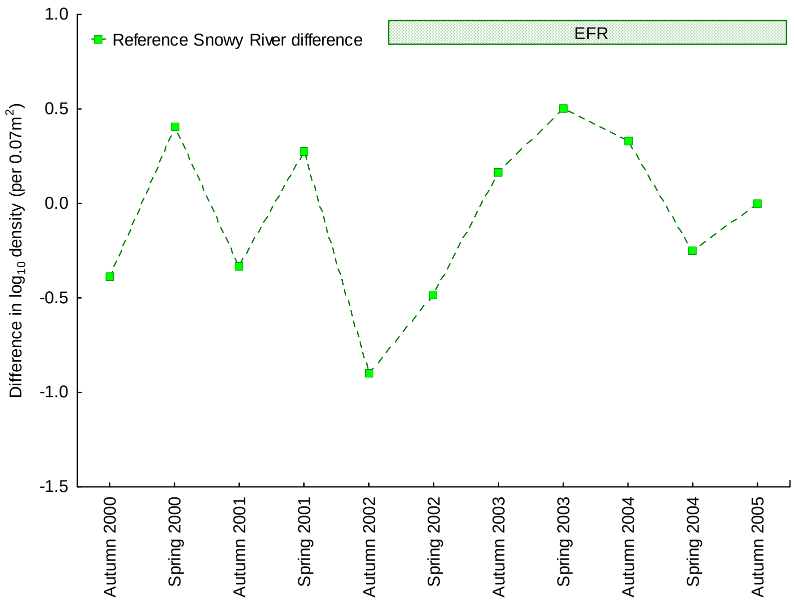


Figure 15. Macroinvertebrate $\log_{10}$ density in midland riffles before and with EFR. a) density in Snowy River and reference sites. b) differences in density between reference and Snowy River sites.

The different site classes (reference, Snowy River) contained different riffle invertebrate assemblages in the midland Snowy River area although the assemblage differences were not as great as riffle reference-Snowy River comparisons in the upland macro-reach nor those found in midland pool edges (Figure 16). The significant patterns in assemblage structure between the reference and Snowy River sites did not appear to change through time except for a reduction in similarity in spring 2001 (Figure 16). The Bray-Curtis similarity returned to levels of approximately 70% after 12 months. The reference site (Site 11) was typified by higher abundances of Sphaeriidae and Gripopterygidae, and the Snowy River site (Site 5) was characterised by higher abundances of Corbiculidae, Baetidae, Hydropsychidae and Simuliidae (Figure 17, SIMPER - Appendix 1, Table A3).

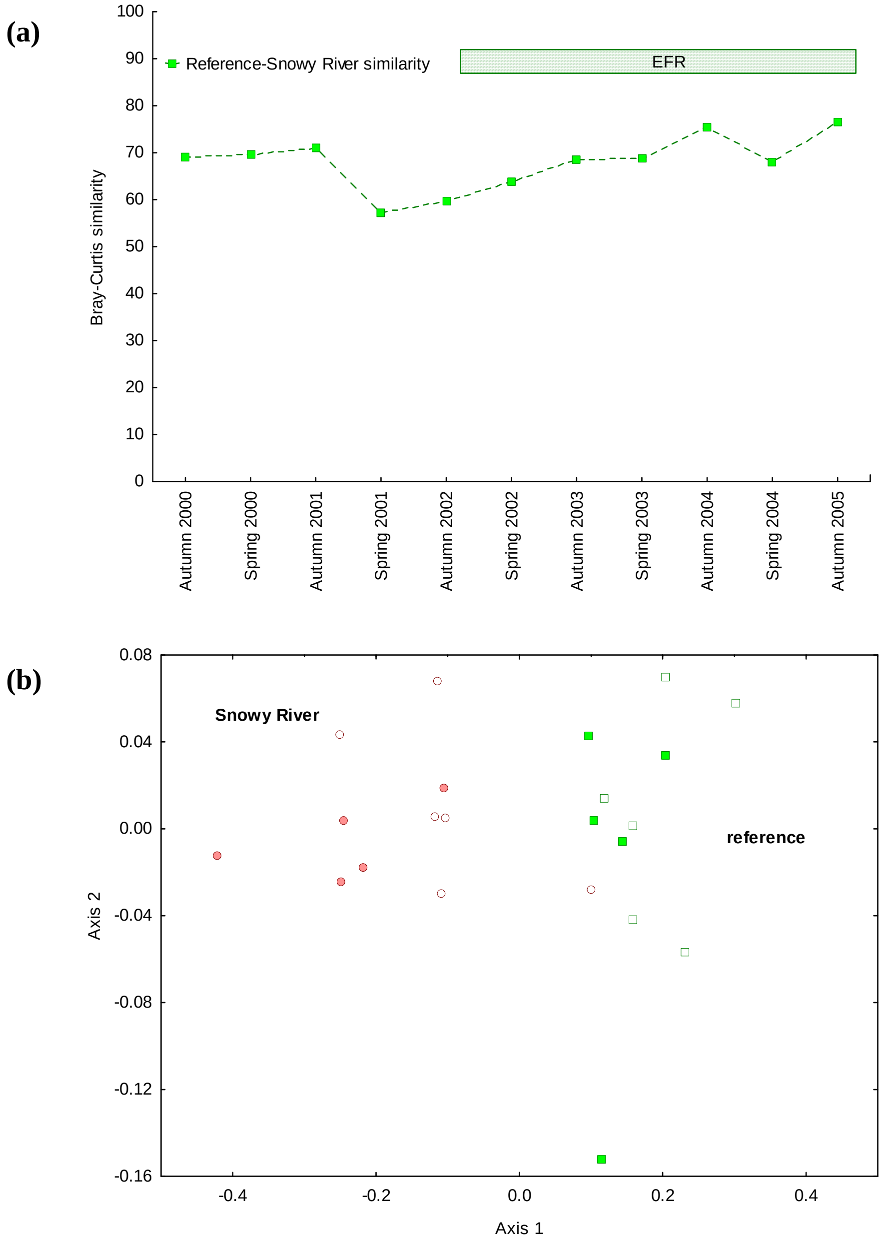


Figure 16. Macroinvertebrate assemblage similarity in midland riffles (Bray-Curtis similarity) before and with EFR. a) mean assemblage similarity between reference and Snowy River sites (error bars ± 1 S.E.), and b) canonical analysis of principal components (CAP) ordination on macroinvertebrate assemblages in Snowy River and reference sites, and before (closed symbols) and with EFR (open symbols).

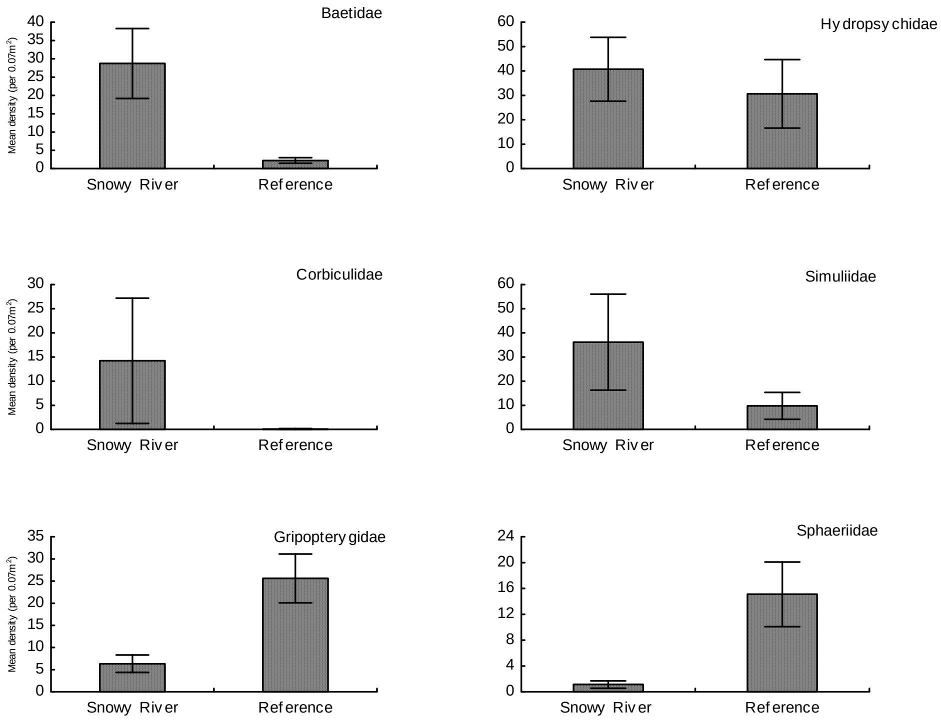


Figure 17. Mean density of macroinvertebrate families from riffles contributing most to differences between midland Snowy River and reference sites (error bars ± 1 S.E.).

3.3.2. Pool edges

A total of 68 invertebrate families were collected from the 2 midland sites from the 11 sampling occasions. The densities of samples ranged from 128 to 1284 individuals per $0.07m^2$.

There was no evidence of serial correlation in any of the response variables and least squares regression with no autocorrelation component was used to test the hypotheses. There were no significant linear or logarithmic trends in assemblage similarity, differences in family richness or differences in density between Snowy River and reference sites throughout the study (Table 7, Figures 18 & 19). Macroinvertebrate family richness was higher in the reference site throughout the study and density was generally higher in the Snowy River site. Hypothesis H_3 was not supported by these results.

Table 7. Summary of linear and logarithmic least squares regression results for macroinvertebrate assemblage similarity, difference in family richness and difference in density ($\log_{10}$) from pool edges in the midland Snowy River and reference sites through time.

		Reference – Snowy River Bray-Curtis similarity	Reference – Snowy River difference in family richnesss	Reference – Snowy River difference in density ($\log_{10}$)
Trend	**d.f.**	**β_0 t value**	**β_0 t value**	**β_0 t value**
linear	1, 9	1.29	1.01	-1.20
logarithmic	1,9	1.79	0.98	-1.45

***P<0.05, ** P<0.01**

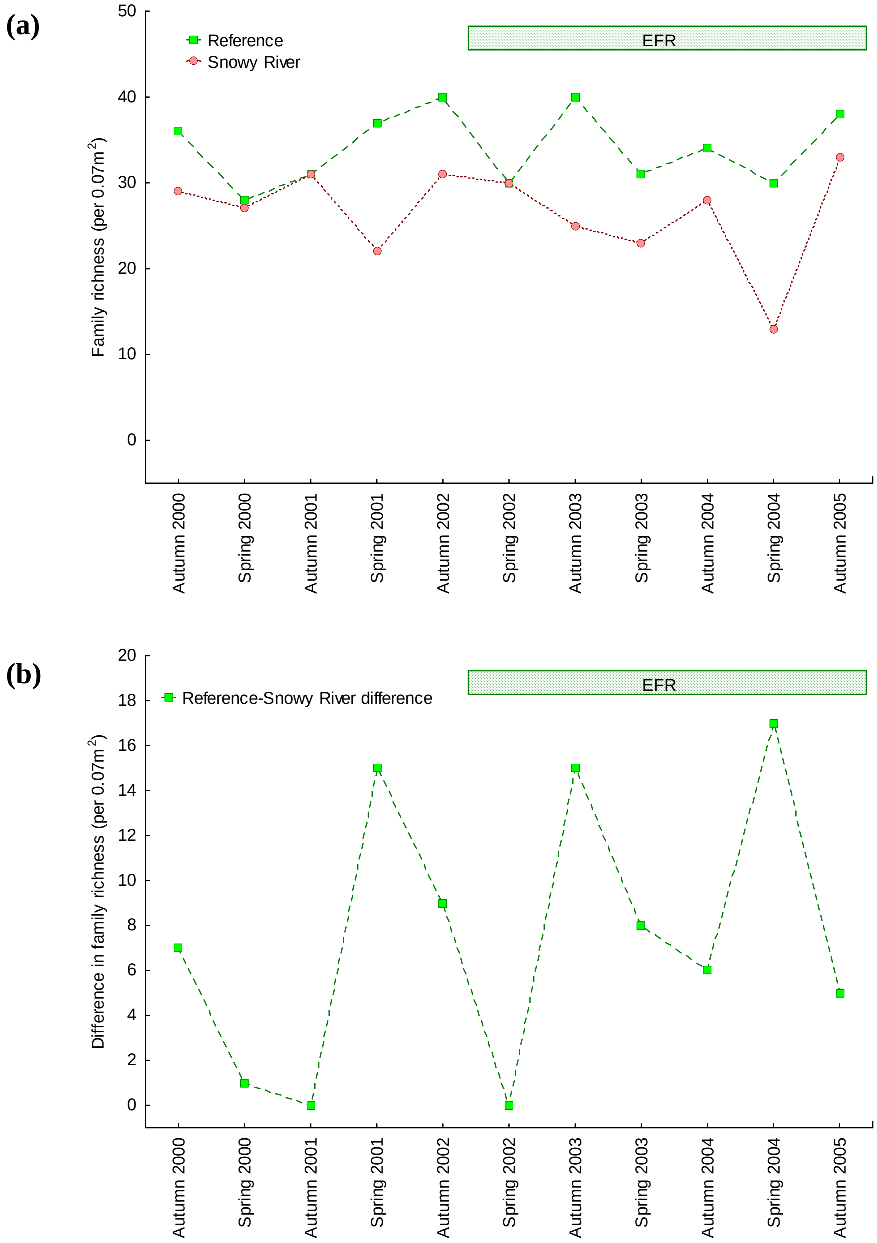
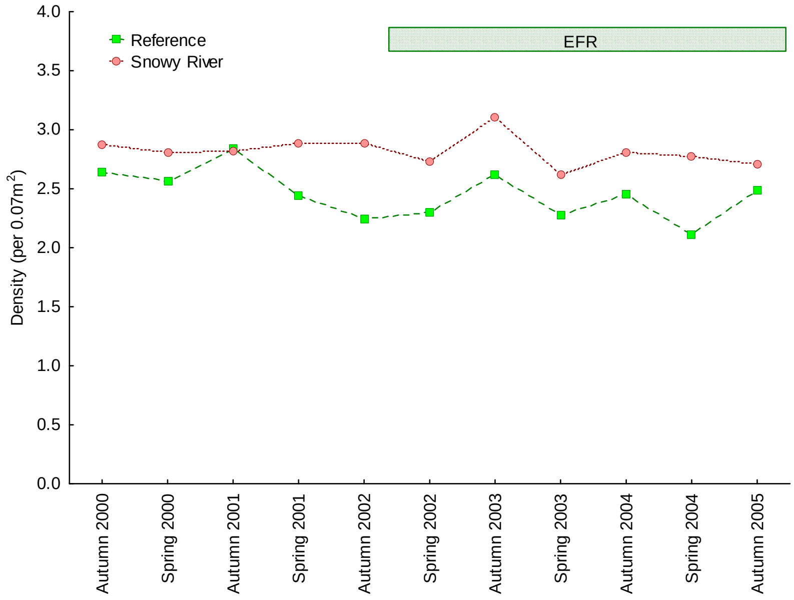


Figure 18. Macroinvertebrate family richness in midland pool edges before and with EFR. a) family richness in Snowy River and reference sites. b) difference in family richness between reference and Snowy River sites.

(a)



(b)

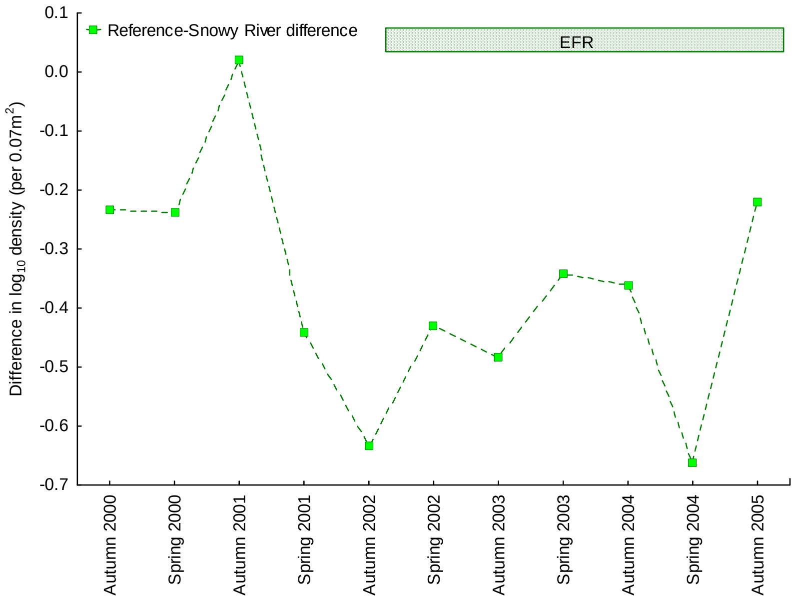


Figure 19. Macroinvertebrate $\log_{10}$ density in midland pool edges before and with EFR. a) density in Snowy River and reference sites. b) difference in density between reference and Snowy River sites.

There were large differences in macroinvertebrate assemblage composition between the Snowy River site and reference site. There was also a clear difference in assemblage composition between the Snowy River site samples collected before the EFR and those with the EFR (Figure 20). Although the Snowy River macroinvertebrate assemblage changed through time, it did not become more similar to those in the reference site as would be expected if H_3 was true. The taxa that distinguished the Snowy River and reference sites are shown in Figure 21 (SIMPER - Appendix 1, Table A4). The Snowy River site had higher densities of Caenidae, Corbiculidae, Chironomidae and Oligochaeta, and the reference site contained higher densities of Planorbidae, Gripopterygidae and Ceinidae.

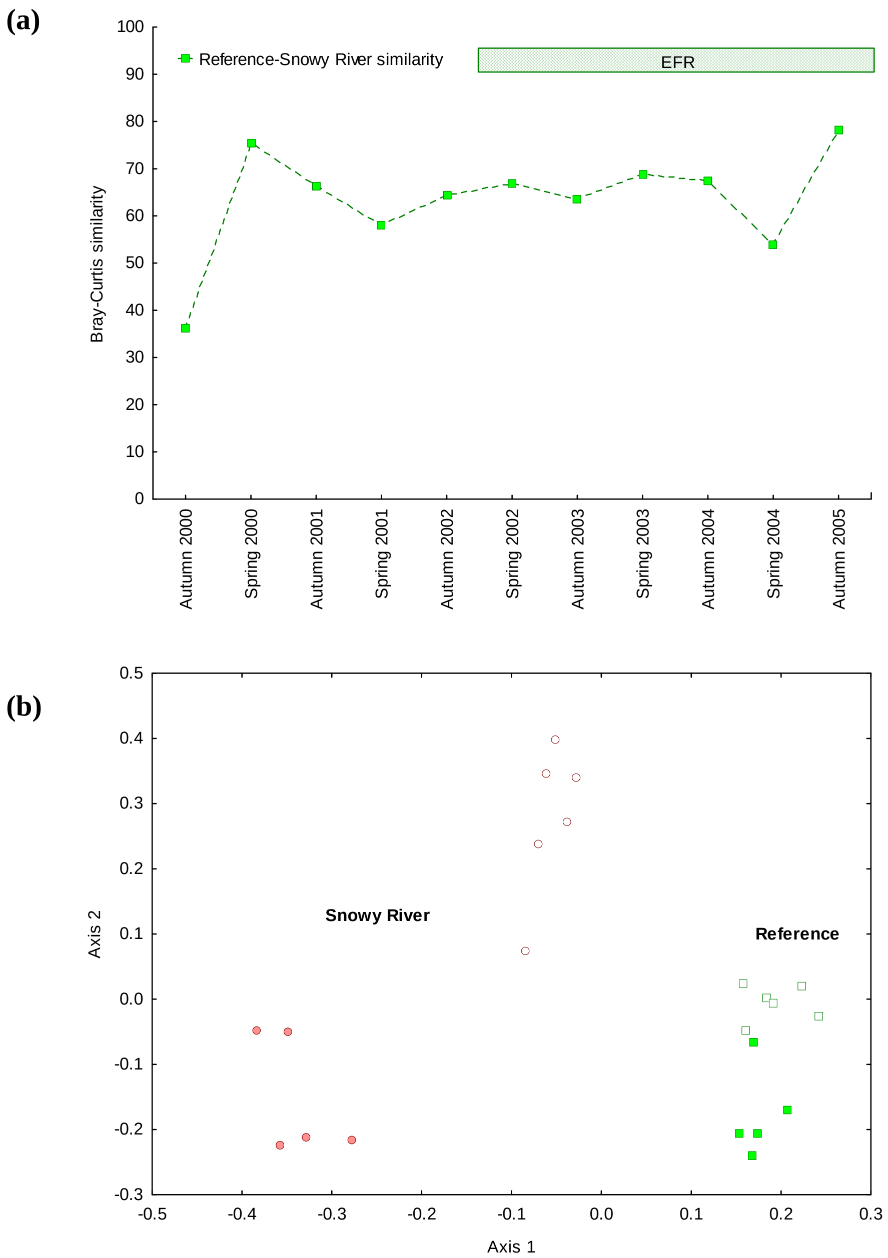


Figure 20. Macroinvertebrate assemblage similarity in midland pool edges (Bray-Curtis similarity) before and with EFR. a) mean assemblage similarity between reference and Snowy River sites (error bars ± 1 S.E.), and b) canonical analysis of principal components (CAP) ordination on macroinvertebrate assemblages in Snowy River and reference sites, and before (closed symbols) and with EFR (open symbols).

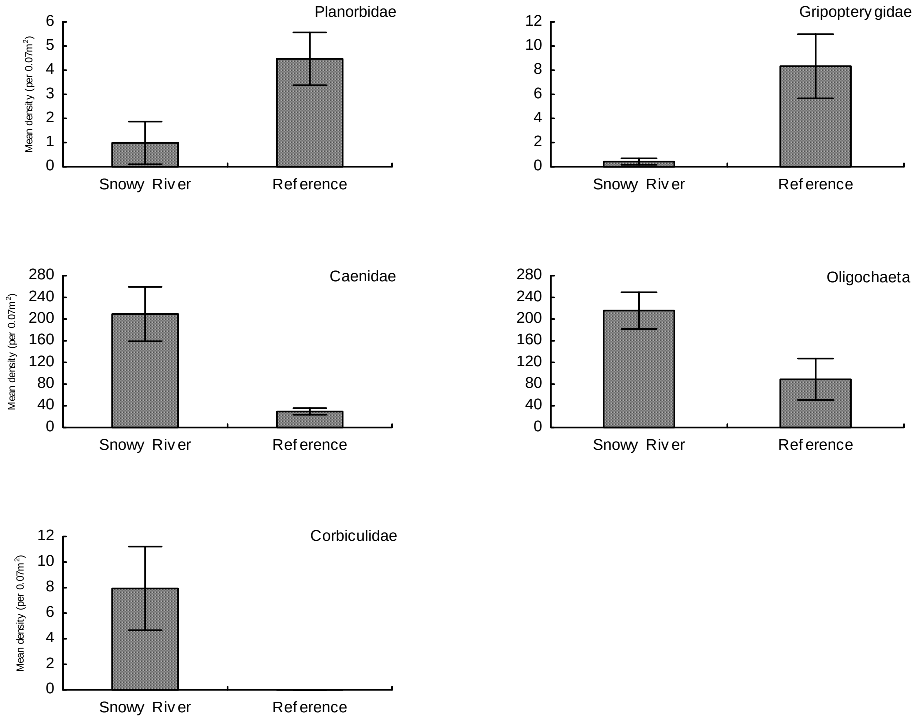


Figure 21. Mean density of macroinvertebrate families from pool edges contributing most to differences between midland Snowy River and reference sites (error bars ± 1 S.E.).

3.4. Lowland Snowy River macro-reach - macroinvertebrate response to EFR

3.4.1. Riffles

A total of 67 invertebrate families were collected within the 5 lowland sites from the 11 sampling occasions. The number of individuals per sample ranged from 23 to 1252 per $0.07m^2$.

The repeated measures ANOVA indicated that there were no significant trends in differences in macroinvertebrate density, family richness or assemblage structure between Snowy River and reference sites through time (Table 8, Figures 22, 23 & 24). Therefore, hypothesis H_4 was not supported by these results. Both invertebrate density and family richness did not differ greatly between the reference and Snowy River sites over the study period.

Table 8. Summary of repeated measures ANOVA results for riffles comparing the macroinvertebrate assemblage similarity, difference in family richness and difference in density (log_{10}) between the lowland Snowy River and reference sites.

		Reference – Snowy River Bray-Curtis similarity		Reference – Snowy River difference in family richnesss		Reference – Snowy River difference in density (log_{10})	
Source of variation	**d.f.**	**MS**	**F**	**MS**	**F**	**MS**	**F**
Linear trend	1	32.09	1.72	54.60	1.94	0.2225	1.0737
Error	2	18.65		28.15		0.2072	
Curvilinear trend	1	43.08	2.53	63.40	2.70	0.2432	1.3847
Error	2	17.01		23.48		0.1757	

***P<0.05, ** P<0.01**

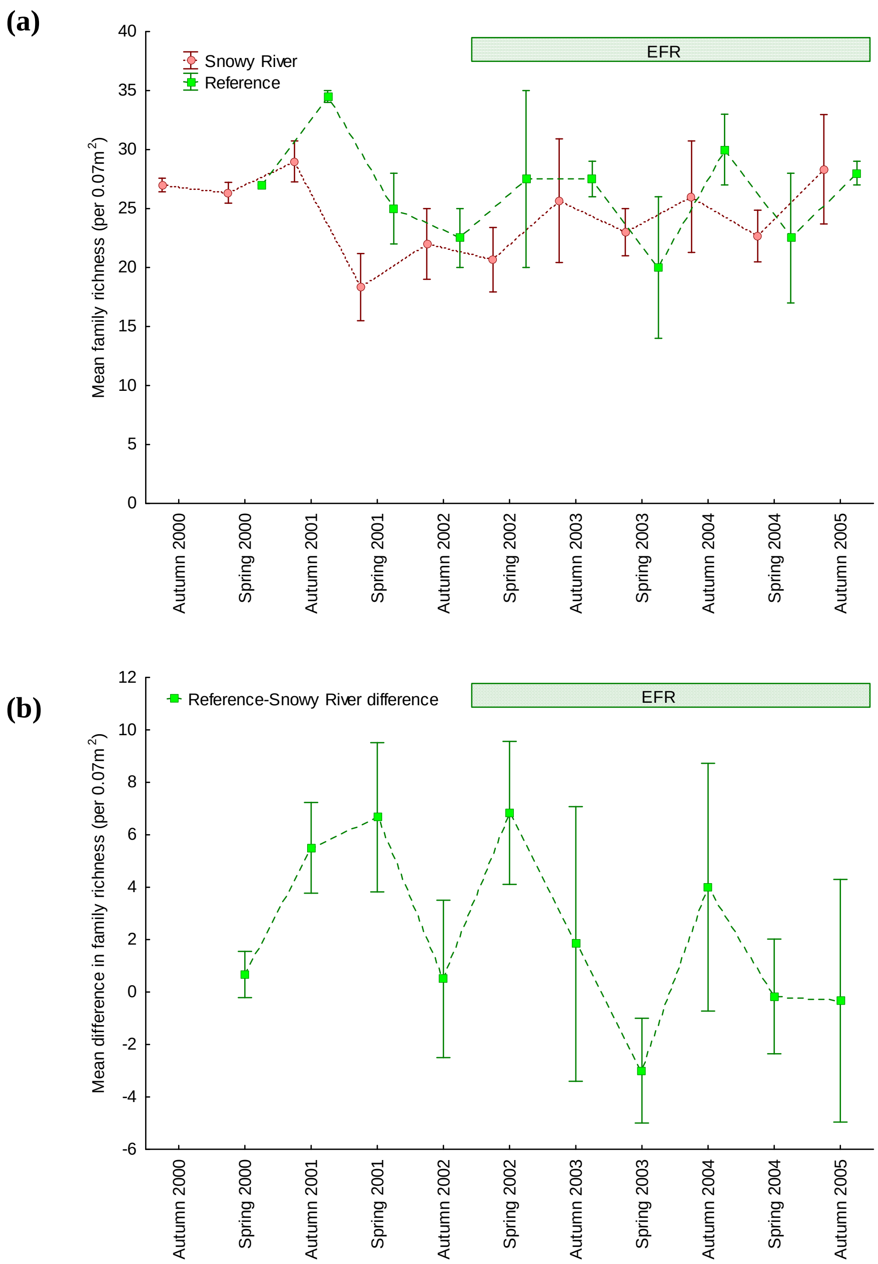


Figure 22. Macroinvertebrate family richness in riffles before and with EFR. a) mean family richness from lowland Snowy River and reference sites, and b) mean difference in family richness between reference and Snowy River sites (error bars ± 1 S.E.).

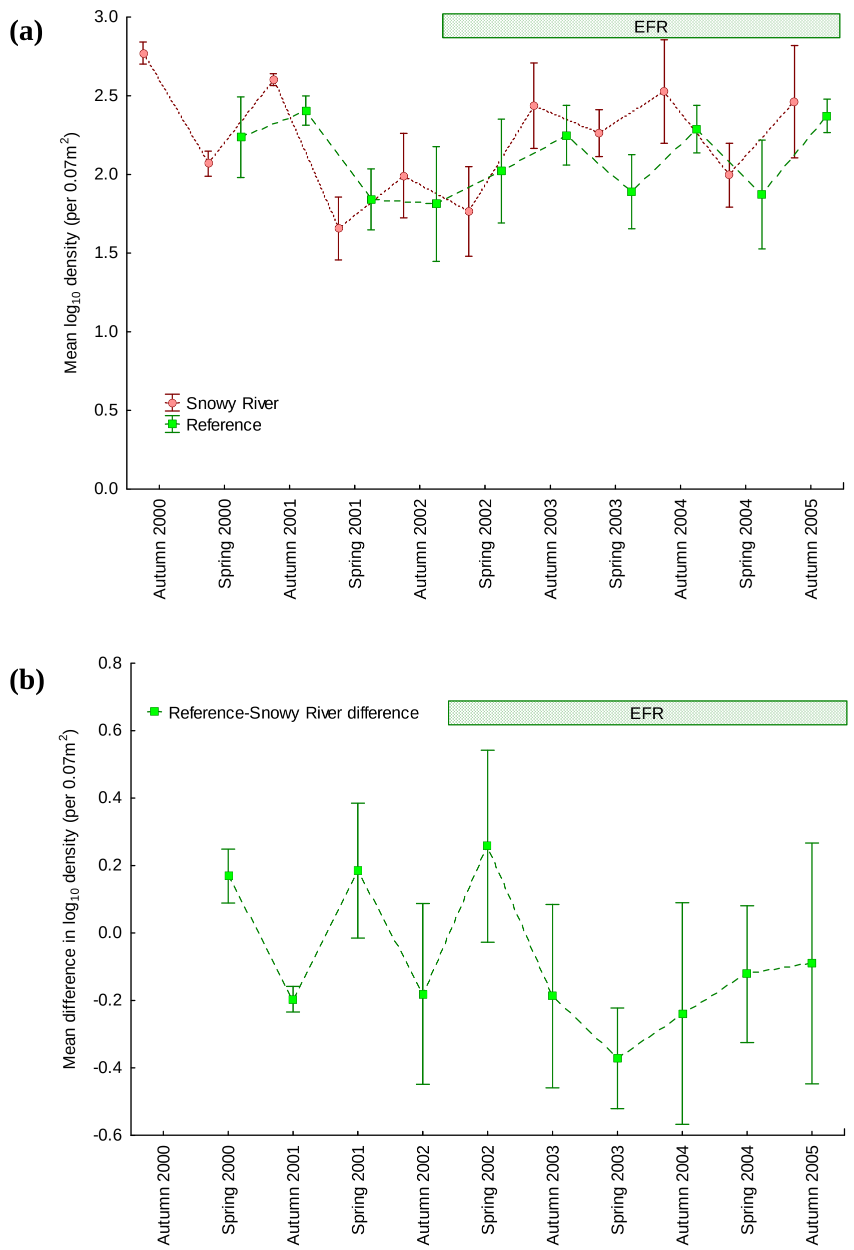


Figure 23. Macroinvertebrate $\log_{10}$ density in riffles before and with EFR. a) mean family richness from lowland Snowy River and reference sites, and b) mean difference in family richness between reference and Snowy River sites (error bars ± 1 S.E.).

There were differences in assemblage structure between the reference and Snowy River sites and also before and with EFR, however the magnitude of the assemblage differences did not change markedly through time (Figure 24). The invertebrate assemblages in the lowland reference and Snowy River sites were less distinct than assemblages collected from the different flow classes in the upland areas.

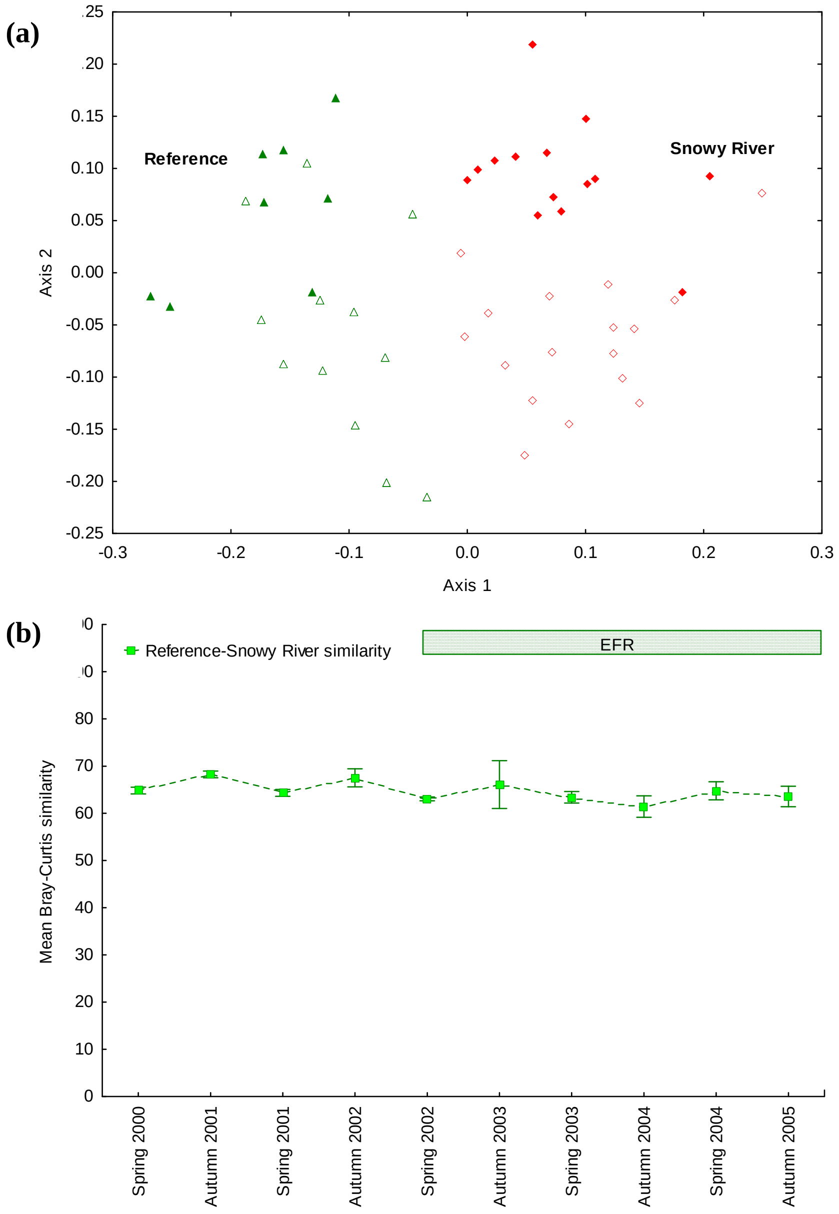


Figure 24. Macroinvertebrate assemblage similarity in lowland riffles (Bray-Curtis similarity) before and with EFR. a) mean assemblage similarity between reference and Snowy River sites (error bars ± 1 S.E.), and b) canonical analysis of principal components (CAP) ordination on macroinvertebrate assemblages from the Snowy River and reference sites, and before (closed symbols) and with EFR (open symbols).

The assemblage differences between the reference and Snowy River sites were attributable to higher densities of Caenidae, Corbiculidae, Simuliidae and larval Elmidae in the Snowy River sites (Figure 25, SIMPER - Appendix 1, Table A5). The reference sites contained higher densities of Gripopterygidae (Figure 25).

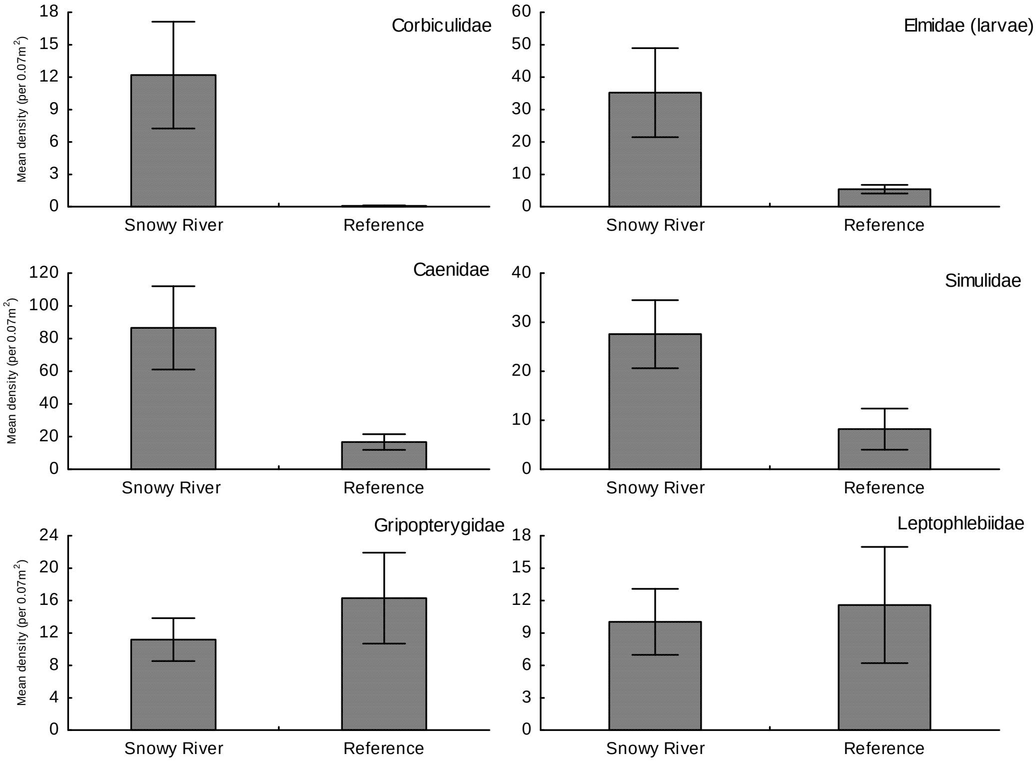


Figure 25. Mean density of macroinvertebrate families from riffles contributing most to differences between lowland Snowy River and reference sites (error bars ± 1 S.E.).

3.4.2. Pool edges

A total of 67 invertebrate families were collected within the 5 lowland sites from the 11 sampling occasions. The number of individuals per sample ranged from 96 to 1681 per $0.07m^2$.

The repeated measures ANOVA indicated that there was a significant negative linear and curvilinear trend in differences in family richness between reference and Snowy River sites through time (Table 9, Figure 26). The mean differences declined from positive (greater richness in reference sites) to negative through time and were attributable to declining family richness in the reference sites and an increase family richness in the Snowy River sites to levels similar to those that occurred from 2000 to 2002. The mean family richness of samples collected from the Snowy River with the EFR was not substantially different than the richness of samples collected before the EFR. There were no significant trends in differences in macroinvertebrate density or assemblage structure (Table 9, Figures 27 & 28). Therefore, hypothesis H_4 was not supported by these results.

Table 9. Summary of repeated measures ANOVA results for pool edges comparing the macroinvertebrate assemblage similarity, difference in family richness and difference in density (log_{10}) between the lowland Snowy River and reference sites.

		Reference – Snowy River Bray-Curtis similarity		Reference – Snowy River difference in family richnesss		Reference – Snowy River difference in density (log_{10})	
Source of variation	**d.f.**	**MS**	**F**	**MS**	**F**	**MS**	**F**
Linear trend	1	3.11	1.42	54.13	**21.57***	0.0887	2.3507
Error	2	2.19		2.51		0.0377	
Curvilinear trend	1	0.05	0.02	36.01	**20.60***	0.1191	4.1193
Error	2	2.49		1.75		0.0289	

***P<0.05, ** P<0.01**

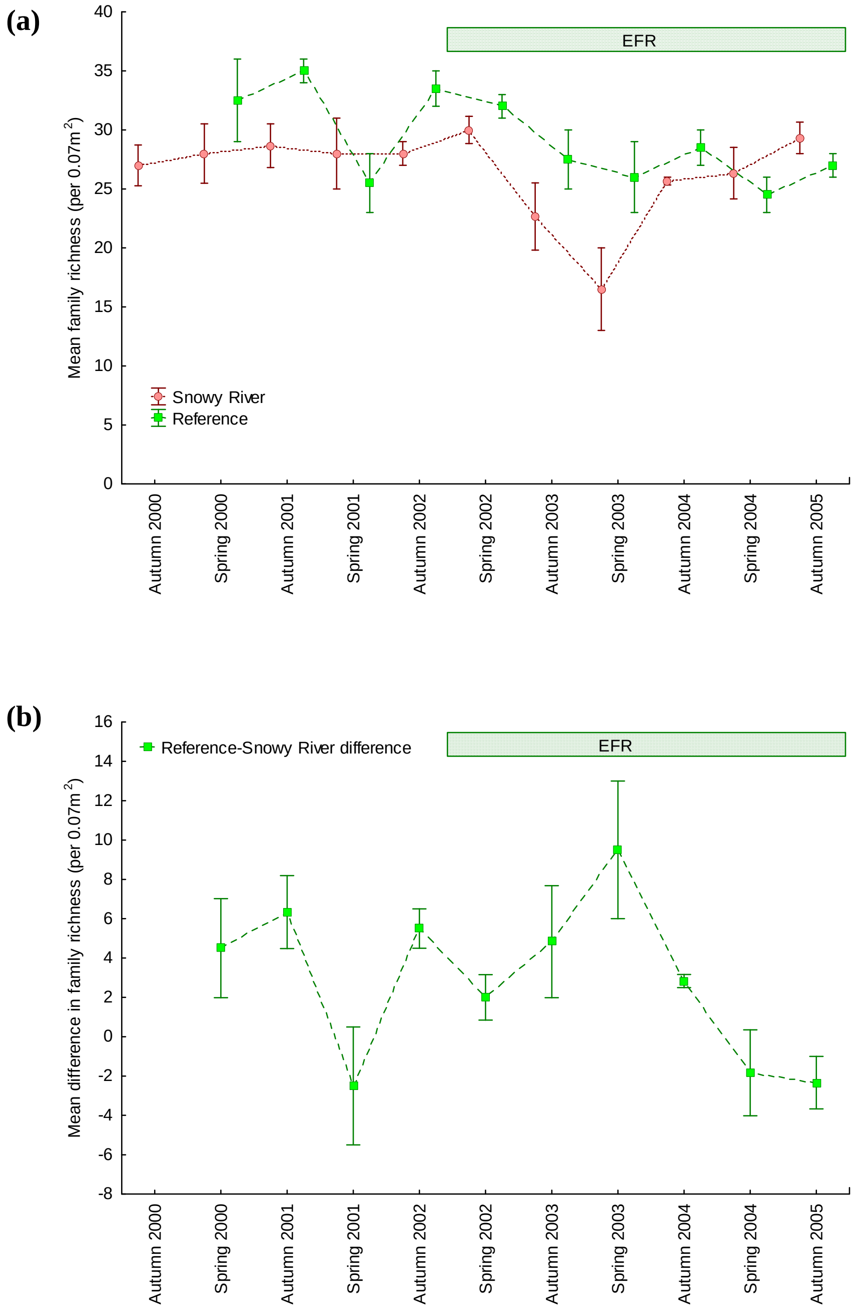


Figure 26. Macroinvertebrate family richness in pool edges before and with EFR. a) mean family richness from lowland Snowy River and reference sites, and b) mean difference in family richness between reference and Snowy River sites (error bars ± 1 S.E.).

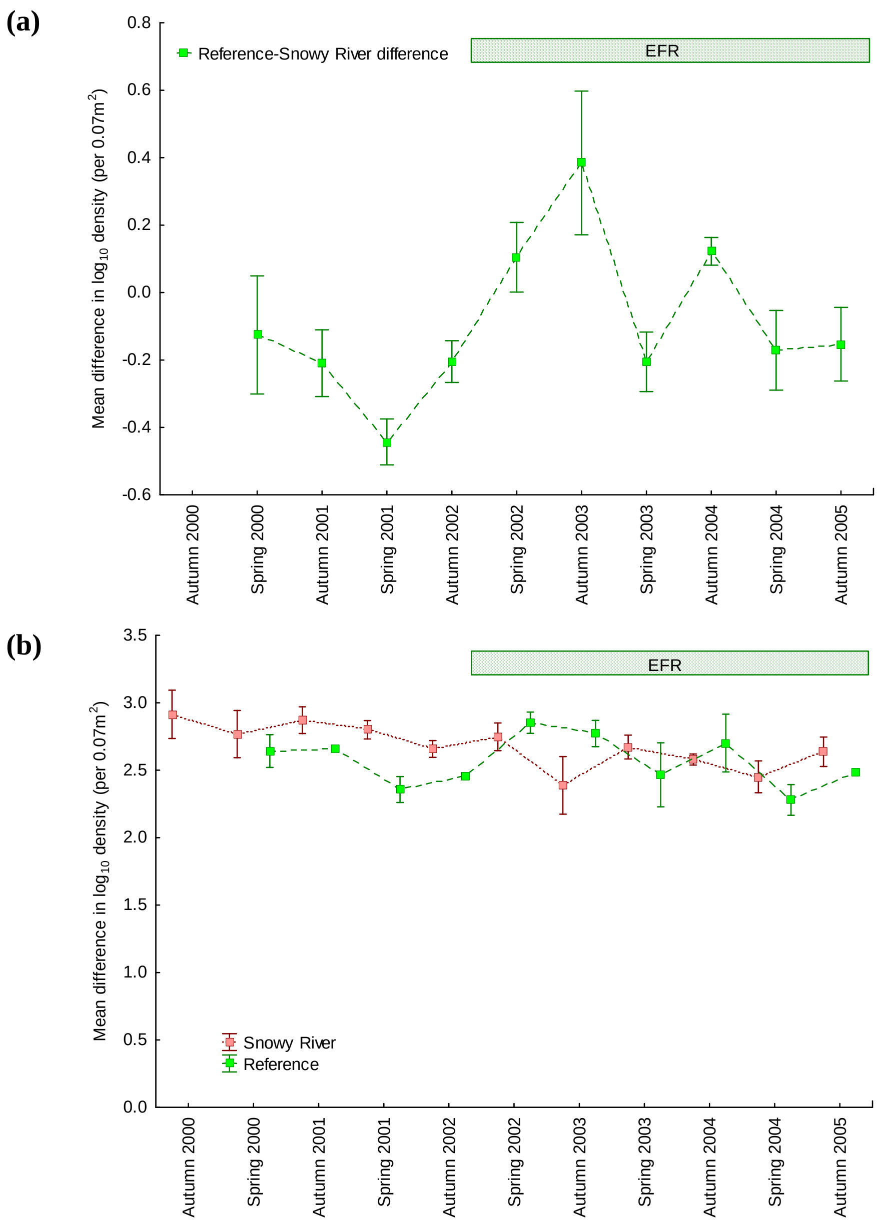


Figure 27. Macroinvertebrate log_{10} density in pool edges before and with EFR. a) mean family richness from lowland Snowy River and reference sites, and b) mean difference in family richness between reference and Snowy River sites (error bars ± 1 S.E.).

There were differences in assemblage structure between the reference and Snowy River sites, and before and with EFR for Snowy River samples (Figure 28). There was also a reduction in reference-Snowy River assemblage similarity in autumn 2003 and spring 2003 which may be attributable to bush fires and subsequent flood in the Snowy River sites in early 2003. This reduced similarity was not apparent in the riffle samples, possibly because sediment and ash deposition occurred to a greater extent in pool edges than in riffles.

The assemblage differences between the reference and Snowy River sites were attributable to higher densities of Corbiculidae and Caenidae in the Snowy River sites (Figure 23, SIMPER - Appendix 1, Table A6). The reference sites contained higher densities of Baetidae and Oligochaeta (Figure 23, SIMPER - Appendix 1, Table A6). The densities of almost all taxa declined in samples with the EFR from the Snowy River with the exception of oligochaete worms, which increased substantially. The overall assemblage similarity between invertebrate fauna sampled from the pool edges of the reference and Snowy River sites was greater than the same comparison in the upland areas.

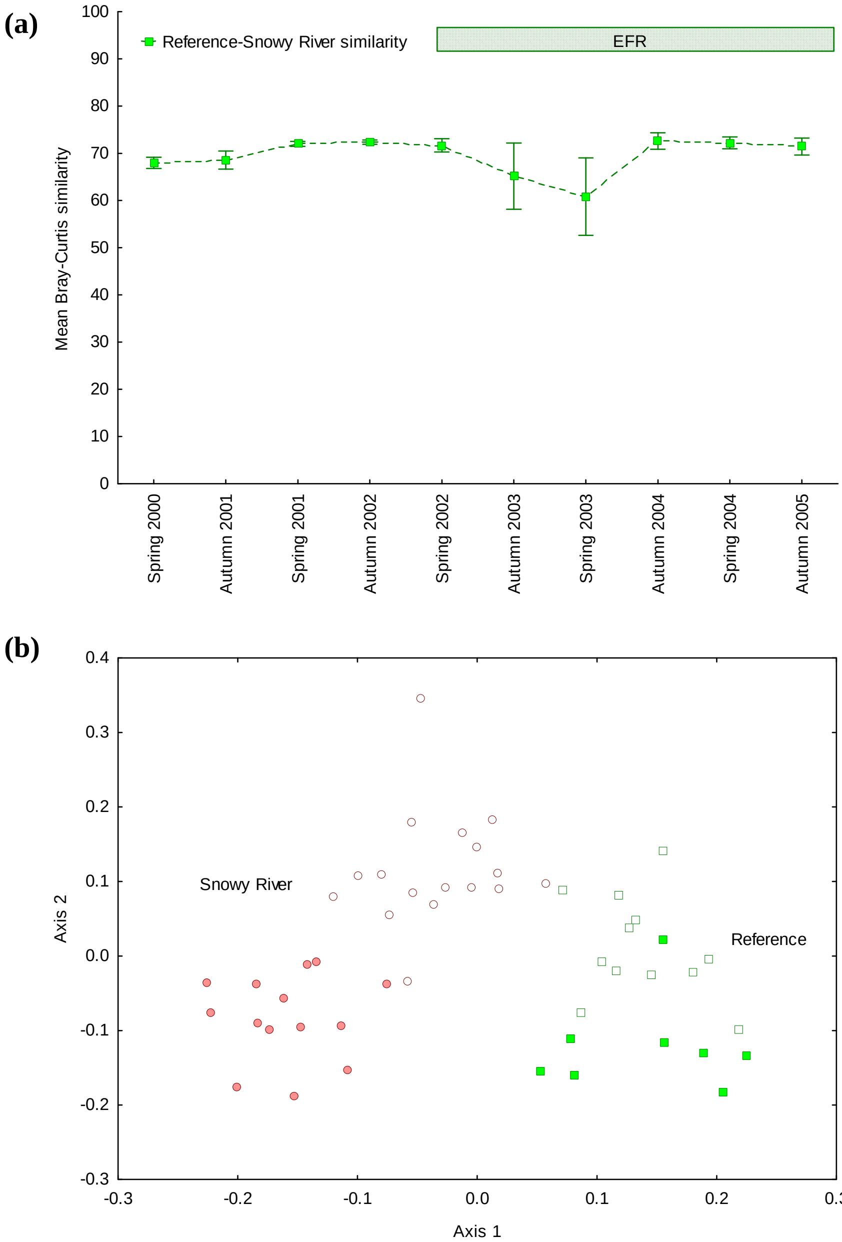


Figure 28. Macroinvertebrate assemblage similarity in lowland pool edges (Bray-Curtis similarity) before and with EFR. a) mean assemblage similarity between reference and Snowy River sites (error bars ± 1 S.E.), and b) canonical analysis of principal components (CAP) ordination on macroinvertebrate assemblages from the Snowy River and reference sites, and before (closed symbols) and with EFR (open symbols).

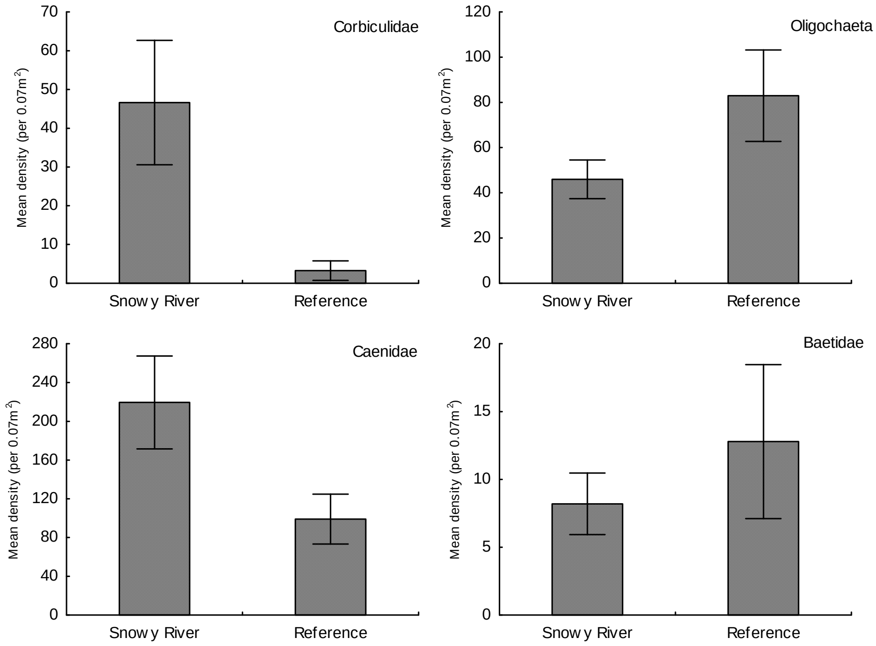


Figure 29. Mean macroinvertebrate density of samples collected from pool edges in the lowland Snowy River and reference sites (error bars ± 1S.E.).

4. Discussion

4.1. Macroinvertebrate response to EFR in the upland Snowy River macro-reach

The macroinvertebrate fauna of pool edges and riffles in the upland reaches of the Snowy River did not become more similar to those in the unregulated reference sites and more dissimilar to assemblages in regulated control sites after the provision of the EFR from decommissioning the Mowamba River aqueduct in August 2002. The macroinvertebrate composition of the Snowy River sites and corresponding reference and control sites were consistently distinct throughout the study period. There was a small increase in the similarity of invertebrate assemblages between the control and Snowy River sites after the provision of EFR, but this pattern was not consistent with the EFR significantly altering the Snowy River assemblage composition as it was expected that the macroinvertebrate assemblage composition would become less similar to those in the control sites and more similar to the fauna in the reference sites. The invertebrate assemblage patterns suggest that the hydrological differences between site classes (reference, control, Snowy River) and natural temporal variations at all sites were more influential in structuring macroinvertebrate assemblages than the increase in stream flows within the Snowy River.

In our study caenid mayflies (riffles) and oligochaete worms (pool edges) were generally typical of the upland regulated Snowy River sites. Other studies have also found greater densities of Caenidae in regulated rivers compared to unregulated rivers (Boon 1988, Pardo *et al.* 1998). Reduced high flows and constant low flows in the upper Snowy River are likely to have favoured high densities of oligochaetes through the build up of silt and organic matter in the pools. Nichols *et al.* (2006) and Petts *et al.* (1993) also found greater densities of segmented worms associated with soft sediments and coarse organic debris in response to river regulation. Chironomids were also numerically dominant in riffles sampled in the regulated Snowy River and control sites (Eucumbene River). This response has been found in many other studies of regulated rivers and has been attributed to an increase of periphytic growth in riffles that increased overall habitat area and food availability (Munn & Brusven 1991, Armitage & Pardo 1995, Growns & Growns 2001, Nichols *et al.* 2006).

Conoesucidae caddisflies (riffles), larval and adult elimids (riffles) and Oniscigastridae (pool edges) distinguished reference sites from regulated Snowy River and Eucumbene River (control) sites. Marchant and Hehir (2002) reported that AUSRIVAS models (>50% probability) predicted Conoesucidae and elmids to be present in the upper Snowy River, but these taxa were not found in their study. The greater density of these taxa in reference sites compared with control and Snowy River sites in our study is consistent with their findings and suggests they have been detrimentally affected by Jindabyne Dam and river regulation. Marchant and Hehir (2002) attribute the absence of these taxa to dams acting as a barrier to drift and limiting recolonisation of these taxa and not to flow regulation. The upper Snowy River sites are all below the confluence of the Mowamba River which provides a pathway for recolonisation of the Snowy River. Therefore, the reduced flow and altered flow regime is likely to be the primary cause of reduced densities of these taxa in the upper Snowy River rather than the barrier effects of Jindabyne Dam. There is little information on the responses of Oniscigastridae to reduced flows and altered flow regimes, but it is probable that an elevated temperature regime combined with lack of suitable sandy edge habitat has reduced their densities in the Snowy River (Scullion, *et al.* 1982, Chessman & Royal 2004, B.Chessman pers. com.).

Phreatoicidae and Leptoceridae (riffles) riffle fauna and Ceinidae (pool edges) were characteristic of the fauna in control sites. The Eucumbene River has no or very little flow and phreatoicids typically occur in springs, seeps, bogs, marshes and other slow flowing wetlands (Campbell *et al.* 1986, G. Wilson pers. com.). Amphipods have also been found to be common in pool edges in streams below dams in Tasmania (Humphries *et al.* 1996). The higher densities of leptocerid caddisflies in riffle habitats within control sites reflect the great reduction in flowing water as this family is usually associated with pool habitats (Boulton & Lake 1992). Hydropsychid caddisflies were found in very low densities in the control sites compared to reference and Snowy River sites, probably due to the almost complete loss of flowing water which would limit their ability to filter small animals and plant material from the water column.

It is difficult to determine the exact mechanisms that are responsible for the altered macroinvertebrate assemblage in the Snowy River compared to the reference sites and also possible reasons for the lack of response of the macroinvertebrate fauna to the EFR. This results from poorly understood knowledge of the biology, life cycles and ecology of most macroinvertebrates (Growns & Growns 2001).

The median daily discharge in the upper Snowy River with EFR was only a third of the flow in the reference rivers and therefore the magnitude of the hydrological change may not have been sufficient to alter the ecological processes or physical habitats that are fundamentally linked to macroinvertebrate composition. For example, water temperatures, a major influence on macroinvertebrate assemblage structure (Munn & Brusven 1991, Quinn *et al.* 1994), remained elevated in the Snowy River with the EFR compared to reference river temperatures during the summer months (Bevitt 2007). Sustained reduction in habitat diversity and area, and constancy of hydraulic habitats are important mechanisms structuring macroinvertebrate assemblages in regulated rivers (Munn & Brusven 1991, Armitage & Pardo 1995, Growns & Growns 2001), and these are also likely to be responsible for the continued distinctiveness of the Snowy River fauna. Low flow variability and magnitude are thought to affect biological processes at the individual macroinvertebrate population level, such as colonisation mechanisms and biotic interactions (Biggs *et al.* 2005). The magnitude of hydrologic changes attributable to the EFR was probably not sufficient to influence these types of biological processes and could possibly explain the absence of a measurable change in macroinvertebrate assemblages. However, the total wetted area and riffle area in the Snowy River (Site 4) increased by approximately 50% with the EFR. It is possible that while macroinvertebrate density, family richness and assemblage composition were not altered greatly by the EFR, total invertebrate abundance in riffle habitats may have increased proportionally. Any change in the total abundance of pool edge fauna is difficult to estimate as the increase in this habitat type was not quantified by the hydraulic modelling, but it is likely that there was some level of increase given the changes in total wetted area of the site.

The frequency, magnitude and duration of high flows within the upper Snowy River have continued to be greatly reduced by Jindabyne Dam after the commencement of EFR and these types of flows are a major determinant of macroinvertebrate assemblage structure (Townsend *et al*. 1997, Lytle & Poff 2004, Biggs *et al.* 2005). These high flow events are believed to structure invertebrate assemblage composition and function through catastrophic disturbance (Lake 2000, Biggs *et al.* 2005). Reductions in high flow events have also been associated with periphyton compositional differences between regulated rivers and unregulated reference rivers and also lower macroinvertebrate grazer densities in the regulated Cotter River in south-east Australia (Chester & Norris 2006). This suggests the EFR in the Snowy River was not sufficient to influence macroinvertebrate assemblage composition through both direct hydrologic disturbance and via alteration of the periphytic food sources for elmids and other grazers. It is unlikely that major changes to macroinvertebrate assemblage structure in the Snowy River will occur until there are significant increases in the frequency, magnitude and duration of high flow events are incorporated into the EFR.

4.2. Macroinvertebrate response to the EFR in the midland and lowland macro-reaches

The macroinvertebrate assemblages within riffle and pool habitats of the midland and lowland reaches of the Snowy River did not respond to the EFR and continued to remain dissimilar to their corresponding reference sites. There were temporal patterns in assemblage composition coincidental with the introduction of the EFR in both midland and lowland macro-reaches, particularly in pool edge habitats, but these were not consistent with the hypothesised effects of the EFR. The hydrological regime of these macro-reaches has been mainly impacted by regulation in the magnitude of high spring snowmelt flows. The variability, seasonality and duration of base flows do not appear to be severely affected by Jindabyne Dam because of the tributary inputs that form a greater proportion of the flow downstream (Morton & Green 2007). In the midland and lowland macro-reaches, the median daily flows were reduced in both the reference and Snowy River sites after EFR began by approximately 40%. These reductions reflect the drought conditions that persisted throughout the region during 2002-2005. The reduction in flows in the Snowy River and reference sites was manifest mainly in reduced number of high flow events. The decreases in the frequency of high flows appear to have affected the macroinvertebrate fauna of the pool edges in the Snowy River to a greater extent than those found in riffles, and also to a greater extent than the macroinvertebrates of the reference sites. The observed biological responses to the drought in Snowy River pool edges were difficult to characterise. In general most taxa declined in density, although others increased, such as oligochaete worms, and the magnitude of the changes appeared to be variable and site specific. Boulton (2003) has reported similar variability in responses to droughts in other rivers, and also that they may not be consistent from year to year. Silt accumulation and increased growth of periphyton may have occurred due to the lack of scouring flows through the pool habitats and limited habitat suitability to tolerant taxa such as oligochaetes. The small EFR provided from Mowamba River may have lessened the effects of the drought slightly and did not have a major effect on the macroinvertebrate fauna in these parts of the Snowy River.

Although there were significant faunal differences between the reference and Snowy River sites over the whole study period, they were unlikely to be attributable to the impact of regulation in the Snowy River. The median daily flows in the Snowy River were much higher than flows in the reference site and much more variable. Therefore the differences in assemblage patterns between the site groupings could be related to the higher flows in the Snowy River. In addition, the use of a single Snowy River site and single reference site in the midland reach limits the monitoring program’s ability to differentiate flow related responses from natural site to site variation. There is some evidence that observed faunal differences were associated more with local factors than hydrological regimes in this macro-reach. Korniushin (2000) has found local geology and substrate characteristics strongly relate to mollusc distribution in other rivers, and the difference in densities of molluscs (Corbiculidae and Sphaeriidae) between the midland Snowy River and reference site are could be related these factors rather than hydrological differences.

Because the reference sites of the midland and lowland macro-reaches are unlikely to possess macroinvertebrate assemblage composition representative of an unregulated Snowy River, it is difficult to determine the extent to which the macroinvertebrate fauna of the Snowy River is affected by regulation. The predictability of the spring snowmelt flows suggests that the life cycles of many macroinvertebrate families in the Snowy River would be linked to these flows, and are therefore likely to be affected by the reduction in magnitudes of spring flows (Poff *et al.*1997, Lytle & Poff 2004, Lake *et al.* 2007). The overall reduction in the magnitude and frequency of high flow events would almost certainly result in a macroinvertebrate assemblage composition that differs substantially than what would be present in the absence of regulation (Townsend *et al.*1997, Lake 2000). Therefore the macroinvertebrate fauna of the midland and lowland macro-reaches of the Snowy River are likely to exhibit significant compositional changes related to EFR only after the reinstatement of large spring flows (Poff *et al.*1997, Lytle & Poff 2004, Lake *et al.* 2007).

It is expected that after the introduction of more significant environmental flows and when the hydrological differences become greater, the macroinvertebrate fauna within the lower Snowy River will become even more dissimilar to the reference sites. The hypotheses for the midland and lowland macro-reaches of the Snowy River (H_3 & H_4) currently state that it is expected that macroinvertebrate assemblages will become more similar to the fauna of the reference sites after environmental flows are provided. This hypothesis should be revised to incorporate the current site class differences, the future hydrological changes and potential increase in biological differences. The reference sites should be considered as unregulated control sites. Therefore, the objective of the EFR will be to alter the macroinvertebrate assemblages of the midland and lowland Snowy River to become more dissimilar to the assemblages of the reference sites.

5. Conclusion

- The median daily flows in the upland macro-reach of the Snowy River increased by 50% after the provision of EFR from the decommissioning of Mowamba River aqueduct. These flows were still substantially lower than the simulated natural flows in the Snowy River for the same period (approximately 94% lower) and about 30% of the flow in the corresponding reference sites. The median daily flows in the midland and lowland macro-reaches of the Snowy River and reference sites reduced by approximately 40% during the period with EFR because of the prevailing drought conditions.
- The macroinvertebrate fauna of the upper Snowy River, reference sites and control sites remained distinct throughout the study due to ongoing alterations to flows in the Snowy River. These biological patterns were not consistent with the EFR altering the Snowy River assemblage composition significantly.
- The continued reduction in habitat diversity and area, and constancy of hydraulic habitats caused by Jindabyne Dam, despite the small increases in flows, are likely to be the principal mechanisms responsible for the upper Snowy River macroinvertebrate assemblages remaining dissimilar to the reference site assemblages. There is unlikely to be a change in the upper Snowy River macroinvertebrate assemblage composition until base flows are increased and high flow events are an integral part of the environmental flow regime.
- Total wetted area and riffle area increased by approximately 50% with the EFR in the upper Snowy River. It is possible that while macroinvertebrate density, family richness and assemblage composition were not altered greatly by the EFR, total invertebrate abundance in riffle habitats may have increased in relation to increased riffle habitat area.
- The macroinvertebrate assemblages within riffle and pool edge habitats of the midland and lowland macro-reaches of the Snowy River did not exhibit any responses that could be related to the introduction of the EFR.
- The macroinvertebrate assemblages of the pool edge habitats within the midland and lowland macro-reaches of the Snowy River exhibited drought related effects. These were declines in densities of most macroinvertebrate families and increased densities of oligochaete worms.
- The faunal differences between the midland and lowland Snowy River and reference site assemblages could be attributed to comparatively higher flows in the Snowy River and site-to-site variation rather than the effects of Jindabyne Dam. The provision of further environmental flows may make the macroinvertebrate assemblages more dissimilar which is contrary to the current hypotheses. The hypotheses for the midland and lowland macro-reaches of the Snowy River (H3 & H4) need to be revised to incorporate the current site class differences, the future hydrological changes and potential increase in biological differences with increases in EFR.
- The macroinvertebrate fauna of the midland and lowland macro-reaches of the Snowy River are only likely to exhibit significant compositional changes related to EFR after the reinstatement of large spring flows.

6. References

Ackerman C.T. (2002). HEC-GeoRAS – An extension for support of HEC-RAS using ArcView GIS. U.S.Army Corps of Engineers.

Anderson M.J. & Willis T.J. (2003). Canonical analysis of principal coordinates: a useful method of constrained ordination for ecology. *Ecology*, **84 (2)**, 511-525.

Armitage P.D and Pardo I. (1995). Impact assessment of regulation at the reach level using macroinvertebrate information from mesohabitats. *Regulated Rivers: research and management* **10**, 147-158.

Bevitt, R., Brooks, A., Dasey, M., Jones, H., Rose, T., Kathuria, A and Chessman, B. (2006) Chapter 7 In: Rose, T. and Bevitt, R. (Eds) (2006) *Specific sampling designs.* Snowy River Flow Response Monitoring Project: Snowy River Recovery, Report No. 3. Department of Natural Resources, NSW.

Bevitt R. (2007). Water quality in the Snowy River before and after the first environmental flow releases from the Mowamba River. *Snowy River Flow Response Monitoring Project*, Report No. 10. ISSN 1449 – 8022, Department of Natural Resources NSW.

Biggs, B. J. F., Vladimar, N. I. and Snelder, T. H. (2005) Linking scales of flow variability to lotic ecosystem structure and function. *River Research and Applications* **21:** 283–298.

Boon P. (1988). The impact of river regulation on invertebrate communities in the U.K. *Regulated Rivers: Research and Management* **2**, 389-409.

Boulton A.J. (2003). Parallels and contrasts in the effects of drought on stream macroinvertebrate assemblages. *Freshwater Biology*, **48**, 1173-1185.

Boulton A.J. and Lake P.S. (1992). The ecology of two intermittent streams in Victoria, Australia. II. Comparisons of faunal composition between habitats, rivers and years. *Freshwater Biology*, **27**, 99-121.

Brooks S. (1994). An efficient and quantitative aquatic benthos sampler for use in diverse habitats with variable flow regimes. *Hydrobiologia* **281**, 123-128.

Bunn S.E. & Arthington A. H. (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management,* **30(4)**, 492-507.

Campbell I.C., McKaige M.E. and Lake P.S. (1986). The fauna of Australian high mountain streams*:* Ecology, Zoogeography and Evolution. In *Flora and Fauna of Alpine Australasia, Ages and Origins.* Ed. B.A. Barlow, CSIRO. Melbourne, 83-104.

Chessman B.C. and Royal M.J. (2004). Bioassessment without reference sites: use of environmental filters to predict natural assemblages of river macroinvertebrates. *Journal of the North American Benthological Society,* **23 (3)**, 599-615.

Chester H. and Norris R. (2006). Dams and flow in the Cotter River, Australia: effects on instream trophic structure and benthic metabolism. *Hydrobiologia* **572**, 275-286.

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

Englund G. and Malvquist B. (1996). Effects of flow regulation, habitat area and isolation on the macroinvertebrate fauna of rapids in north Swedish rivers. *Regulated Rivers: Research and Management* **12**, 433-445.

ESRI 1999. *Arcview 3D Analyst User Manual*. Environmental Systems Research Institute Incorporated, California, USA. 118 pp.

Growns I.O. and Growns J.E. (2001). Ecological effects of flow regulation on macroinvertebrate and periphytic diatom assemblages in the Hawkesbury- Nepean River, Australia. *Regulated Rivers: Research and Management* **17**, 275-293.

Hawking J.H. (2000). Key to Keys. *A guide to keys and zoological information to identify invertebrates from Australian inland waters*. Identification Guide No. 2, Second edition. Murray Darling Freshwater Research Centre and Cooperative Research Centre for Freshwater Ecology.

Humphries P., Davies P.E. and Mulcahy M.E. (1996). Macroinvertebrate assemblages of littoral habitats in the Macquarie and Mersey Rivers, Tasmania: implications for the management of regulated rivers. *Regulated Rivers: Research and Management* **12**, 99-122.

Jowett I.G. (1993). A method for objectively identifying pool, run and riffle habitats from physical measurements. *New Zealand Journal of Marine and Freshwater Research* **27**, 241-248.

Korniushin A.V. (2000). Review of the Family Sphaeriidae (Mollusca: Bivalvia) of Australia, with the description of four new species. *Records of the Australian Museum*, **52**, 41-102.

Lake P.S. and Marchant R. (1990). Australian upland streams: ecological degradation and possible restoration. *Proceedings of the Ecological Society of Australia*, **16**, 79-91.

Lake P.S. (2000). Disturbance, patchiness and diversity in streams. *Journal of the North American Benthological Society*, **19**, 573-592.

Lake P.S., Bond N. and Reich P. (2007). Linking ecological theory with stream restoration. *Freshwater Biology*, **52**, 597-615.

Lytle D.A. and Poff N.L. (2004). Adaptation to natural flow regimes. *Trends in Ecology and Evolution*, **19**, 94-100.

Magilligan F.J. and Nislow K.H. (2005). Changes in hydrologic regime by dams. *Geomorphology* **71**, 61-78.

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

Marchant R. and Hehir G. (2002). The use of AUSRIVAS predictive models to assess the response of lotic macroinvertebrates to dams in south-east Australia. *Freshwater Biology* **47**, 1033-1050.

Morton S. & Green D. (2007). Hydrology. Snowy River Flow Response Monitoring Project, Report No. 9. ISSN, Department of Natural Resources NSW.

Munn M.D. and Brusven M.A. (1991). Benthic macroinvertebrate communities in nonregulated and regulated waters of the Clearwater River, Idaho, U.S.A. *Regulated Rivers: Research and Management* **6**, 1-11.

Nichols S., Norris R., Maher W. and Thoms M. (2006). Ecological effects of serial impoundment on the Cotter River, Australia. *Hydrobiologia* **572**, 255-273.

Pardo I. Campbell I.C. and Brittain J.E. (1998). Influence of dam operation on mayfly assemblage structure and life histories in two south-eastern Australian streams. *Regulated Rivers: Research and Management* **14**, 285-295.

Petts G.E. (1984). *Impounded Rivers: Perspectives for Ecological Management*. John Wiley and Sons, New York.

Petts G., Armitage P. and Castella E. (1993). Physical habitat changes and macroinvertebrate response to river regulation: the River Rede, UK. *Regulated River: Research and Management*, **8**, 167-178.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. and Stomberg, J.C. (1997). The natural flow regime: a paradigm for river conservation and restoration. *BioScience* **47**, 769–784.

Pringle C.M., Freeman M.C. and Freeman B.J. (2000). Regional effects of hydrologic alterations on riverine macrobiota in the New World: tropical-temperate comparisons. *BioScience*, **50**, 807-823.

Quinn J.M., Cooper A.B., Davies-Colley R.J., Rutherford J.C. and Williamson R.B. (1994). Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research*, **31**, 579-597.

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

Rader R.B. and Belish T.A. (1999). Influence of mild to severe flow alterations on invertebrates in three mountain streams. *Regulated Rivers: Research and Management* **15**, 353-363.

Reinfelds I., Haeusler T., Brooks A.J. and Williams S. (2004). Refinement of the wetted perimeter breakpoint method for setting cease-to-pump limits or minimum environmental flows. *River Research and Applications* **20**, 671-685.

Scullion J, Parish C.A., Morgan N. and Edwards R.W. (1982). Comparison of benthic macroinvertebrate fauna and substratum composition in riffles and pools in the impounded River Elan and the unregulated River Wye, mid-Wales. *Freshwater Biology* **12**, 579-595.

Thomson J.R. (2002). The effects of hydrological disturbance on the densities of macroinvertebrate predators and their prey in a coastal stream. *Freshwater Biology* **31**, 1333-1351.

Townsend C.R., Scarsbrook M.R. and Dolédec S. (1997). Quantifying disturbance in streams: alternative measures of disturbance in relation to macroinvertebrate species traits and species richness. *Journal of the North American Benthological Society* **16 (3)**, 531-544.

7. Appendix

Table A1. Similarity percentages procedure (SIMPER) determining taxa contributing the most to differences in riffle invertebrate assemblage structure between Snowy River sites (Sites 1-4) and reference sites (12 & 13) and control sites (22 & 23).

Taxon contributing dissimilarity	Mean abundance per sample		Ratio (mean dissimilarity / SD)	Cumulative Contribution (%)
	Reference	**Snowy River sites**		
Conoesucidae	26.49	0.08	3.08	6.58
Caenidae	2.56	66.57	1.54	11.60
Elmidae	37.84	1.86	1.57	15.71
Elmidae (adult)	9.17	0.23	1.66	19.65
Hydropsychidae	27.23	24.24	1.25	23.31
Chironomidae	29.27	71.39	1.39	26.86
	Control	**Snowy River sites**		
Leptophlebiidae	14.75	0.20	2.76	5.47
Hydropsychidae	0.67	24.24	1.73	10.03
Phreatoicidae	6.26	0.05	2.14	14.55
Leptoceridae	7.21	0.23	2.05	18.76
Ceinidae	6.39	0.13	1.77	22.87
Caenidae	4.00	66.57	1.62	26.85
	Control	**Reference**		
Conoesucidae	0.25	26.49	2.53	4.66
Phreatoicidae	6.26	0	2.18	8.63
Hydropsychidae	0.67	24.24	1.82	12.59
Baetidae	0.07	8.10	2.28	16.29
Elmidae	0.52	37.84	1.73	19.93
Leptoceridae	7.21	0.39	1.94	23.53

Table A2. Similarity percentages procedure (SIMPER) determining taxa contributing the most to differences in pool edge invertebrate assemblage structure between Snowy River sites (1-4) and reference sites (12 & 13) and control sites (22 & 23).

Taxon contributing dissimilarity	Mean abundance per sample		Ratio (mean dissimilarity / SD)	Cumulative Contribution (%)
	Reference	**Snowy River sites**		
Oligochaeta	25.22	203.03	1.53	4.91
Oniscigastridae	17.33	0.05	0.90	8.64
Elmidae (larvae)	11.60	1.64	1.43	12.16
Baetidae	9.23	0.98	1.60	15.66
Tricladida	0.10	6.43	1.49	19.08
Gripopterygidae	4.58	0.62	1.64	22.34
Caenidae	11.45	40.82	1.38	25.37
	Control	**Snowy River sites**		
Leptophlebiidae	19.32	2.47	1.62	4.14
Odontoceridae	4.68	2.24	2.18	8.18
Oligochaeta	66.15	203.03	1.32	12.06
Lestidae	1.90	0.02	2.99	15.74
Gomphidae	0.20	6.05	1.94	19.38
Phreatoicidae	3.50	0.92	1.69	22.87
Leptoceridae	21.96	5.52	1.46	26.27
	Control	**Reference**		
Lestidae	1.90	0	3.76	3.80
Ceinidae	4.82	0.03	1.98	7.48
Oniscigastridae	0.08	17.33	0.92	11.12
Odontoceridae	4.68	0.26	2.00	14.61
Phreatoicidae	3.50	0.05	1.82	18.07
Leptophlebiidae	19.32	4.64	1.52	21.45
Leptoceridae	21.96	1.58	2.03	24.77

Table A3. Similarity percentages procedure (SIMPER) determining taxa contributing the most to differences in midland riffle invertebrate assemblage structure between Snowy River site (Site 5) and reference site (Site 11).

Taxon contributing dissimilarity	Mean abundance per sample		Ratio (mean dissimilarity / SD)	Cumulative Contribution (%)
	Reference	**Snowy River site**		
Sphaeriidae	15.11	1.14	1.69	5.41
Corbiculidae	0.09	14.23	1.51	10.06
Baetidae	2.24	28.73	1.74	14.66
Hydropsychidae	30.67	40.74	1.45	18.81
Simuliidae	9.82	36.15	1.19	22.91
Gripopterygidae	25.62	6.35	1.94	26.23

Table A4. Similarity percentages procedure (SIMPER) determining taxa contributing the most to differences in midland pool edge invertebrate assemblage structure between Snowy River site (Site 5) and reference site (Site 11).

Taxon contributing dissimilarity	Mean abundance per sample		Ratio (mean dissimilarity / SD)	Cumulative Contribution (%)
	Reference	**Snowy River site**		
Caenidae	29.61	209.32	2.11	5.06
Corbiculidae	0	7.94	2.31	9.41
Oligochaeta	88.95	215.65	1.62	13.34
Planorbidae	4.47	0.98	2.18	16.88
Gripopterygidae	8.32	0.42	1.71	20.38
Ceinidae	2.91	1.61	1.78	23.42
Chironomidae	67.59	130.27	1.30	26.42

Table A5. Similarity percentages procedure (SIMPER) determining taxa contributing the most to differences in lowland riffle invertebrate assemblage structure between Snowy River sites (sites 6, 7 & 8) and reference sites (sites 25 & 26).

Taxon contributing dissimilarity	Mean abundance per sample		Ratio (mean dissimilarity / SD)	Cumulative Contribution (%)
	Reference	**Snowy River site**		
Hydropsychidae	22.75	33.93	1.36	4.66
Caenidae	16.72	86.55	1.36	9.12
Corbiculidae	0.08	12.19	1.21	13.05
Simuliidae	8.21	27.59	1.33	16.96
Gripopterygidae	16.30	11.18	1.21	20.19
Elmidae (larvae)	5.43	35.23	1.24	23.30
Leptophlebiidae	11.59	10.03	1.18	26.37

Table A6. Similarity percentages procedure (SIMPER) determining taxa contributing the most to differences in lowland pool invertebrate assemblage structure between Snowy River sites (sites 6, 7 & 8) and reference sites (sites 25 & 26).

Taxon contributing dissimilarity	Mean abundance per sample		Ratio (mean dissimilarity / SD)	Cumulative Contribution (%)
	Reference	**Snowy River site**		
Corbiculidae	3.26	46.62	1.65	6.20
Caenidae	99.08	215.50	1.29	10.62
Baetidae	12.79	8.20	1.26	14.02
Oligochaeta	82.98	45.97	1.39	17.37
Leptophlebiidae	12.31	11.71	1.28	20.69