SNOWY RIVER RECOVERY

SNOWY RIVER FLOW RESPONSE MONITORING

CHANGES IN FISH ASSEMBLAGES AFTER THE FIRST FLOW RELEASES TO THE SNOWY RIVER DOWNSTREAM OF JINDABYNE DAM

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Snowy River Recovery
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Changes in fish assemblages after the first flow releases to the Snowy River downstream of Jindabyne Dam

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Abstract

Since construction of the Snowy Mountains Scheme (SMS) in 1967, flows in the Snowy River have been diverted into the Murray and Murrumbidgee Rivers, with an average of only 1% or 4% of Mean Annual Natural Flows (MANF) being recorded in the Snowy River at Jindabyne or Dalgety respectively. This has caused dramatic changes to river processes, instream habitats and the distribution and abundance of fish throughout the Snowy River system.

It is expected that releasing environmental water (ie. 21% MANF) to repair the flow regime of the Snowy River may result in positive changes in native fish populations. Although little has been documented on the response of fish to environmental water releases, the most fundamental outcomes of a more natural flow regime on fish populations include the protection of low flow habitats, provision of spawning triggers, improved conditions for fish recruitment, greater habitat diversity supporting increased species richness and increased opportunities for fish passage across flow induced barriers.

This report documents the condition of fish assemblages in both Snowy River sites (test sites) and unregulated tributary streams (reference sites) for:

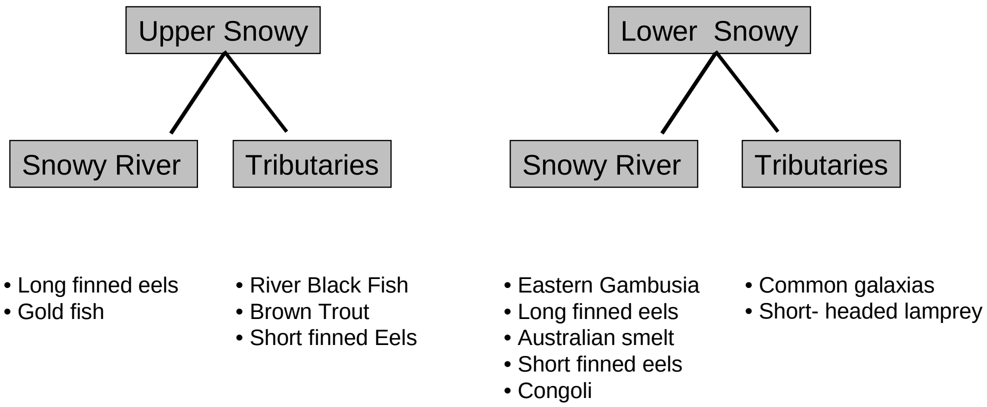
- o the three years before the release of environmental flows (February - March 2000, 2001 and 2002), and
- o the three years after the implementation of the first stage of incremental environmental flow releases to the Snowy River (January - March 2003, 2004 and 2005).

Before environmental flows were released from the SMS, the hydrology in test and reference sites differed in each of the upland, midland and lowland zones of the catchment that were used to sample macroinvertebrates (Brooks *et al.* 2007). In the upland macro-reach, median flows in the Snowy River were much lower than flows in the tributary streams. However, in the midland and lowland zones, median flows in the Snowy River were higher due to the cumulative contributions of tributary streams. The median discharge in the midland and lowland macro-reaches of the Snowy River were about double and four times of those in tributaries.

Before the release of environmental water, the fish assemblage was clearly divided into two components (Figure A): that which occurred in the upper catchment (above Snowy Falls) and that in the lower catchment (below Snowy Falls). The major differences between the two zones were the low abundance or absence of diadromous migratory fish (except eels) and the greater abundance of short-finned eel and trout in the upper catchment, and the greater abundance of Australian smelt, congoli and long-finned eel below Snowy Falls. These upper and lower zone differences were greater than the differences between un-regulated tributary streams (reference sites) and the highly regulated main channel of the Snowy River (test sites) within either zone, which were also significantly different prior to the release of flows. In the upper catchment, river blackfish, brown trout and short-finned eel were more abundant in un-regulated tributary streams, whilst long-finned eel and goldfish were more abundant in the regulated upper part of the Snowy River. These patterns may be a response of the

three times greater median flows in upper catchment reference reaches than in the Snowy River channel (Brooks *et al.* 2007). In the lower zone, eastern gambusia, long-finned eel, Australian smelt, short-finned eel and congoli were all more abundant in Snowy River test sites while common galaxias and short-headed lamprey were more abundant at reference sites. These patterns in fish assemblages in the lower reaches were probably a response to the less altered flow regime in the Snowy River catchment, the absence of major barriers and local habitat preferences.

Figure A. Grouping of fish samples collected in the Snowy River system 2000-2005 and the common fish species represented in these groupings.



The allocation of 21% MANF environmental water to the Snowy River should increase flows at all test sites. The first flow release from 1.9% to 3.4% MANF as measured at Dalgety has not increased flows at all sites, partly because the river system was influenced by a severe drought during the environmental flow period and tributary contributions were considerably reduced. Only the Snowy River sites in the upper reaches experienced a small increase in base flows and flows at midland and lowland zone test sites actually declined. Therefore, the hypothesised responses for fish assemblages to increased flows in the lower zone were unlikely to eventuate between 2003 and 2005.

Given the small environmental water release and the prolonged drought, the fish assemblage of the Snowy River has not become more similar to the reference sites. None of the following indices responded to the provision of flows in the direction expected at 21% MANF: native species richness, the proportion of individuals that were native species, population size structures, the abundance of trout, the proportion of individuals that were pest species or the abundance of each individual taxa.

Only Southern pygmy perch increased in abundance at Snowy River sites, but it remained stable (or declined) in abundance at reference sites. However, because the change in abundance was coincident with declining flows at both reference and test sites in the lowland macro-reach, the result is contrary to the expected response to flow provision. Southern pygmy perch are generally considered a still water or wetland species (Kuiter *et al.* 1996), and the increase in their abundance at test sites may have been a direct result of the 60% decline in median flows in the lower Snowy River. In future as environmental water flows return to average or greater volumes in the lowland macro-reaches of the Snowy River, it is expected that the abundance of Southern pygmy perch at tests sites may decline.

The limited response observed for fish assemblages following the release of environmental water releases is consistent with the results reported for macroinvertebrate assemblages (Brooks *et al*. 2007). The environmental flows released from the Mowamba River between 2003 and 2005 were not sufficient to influence fish assemblage composition in either the upper or lower catchment in the direction expected.

It is unlikely that the 2003 bushfires compromised the ability to detect changes resulting from increased environmental flows.

In future, continued sampling through time is needed to detect changes from increased environmental water releases. Additionally, predictive ecological modelling combined with the monitoring program may be needed to better define the future response of fish assemblages to the new flow regime.

1. Introduction

The Snowy Mountains Scheme (SMS) was designed for the dual purpose of hydro-electric power generation and the provision of a reliable water resource to irrigators in the Murray and Murrumbidgee valleys (SnowyHydro 2007). The SMS involved the construction of weirs and aqueducts in the upper Snowy catchment between 1955 and 1967. Since completion, the scheme had diverted approximately 99% of Mean Annual Natural Flow (MANF) from the Snowy River at Jindabyne, or 96% of MANF at Dalgety (Morton *et al*, in prep.), severely altering the hydrology of the river (Figure 1).

Although the hydrological effects of the SMS lessen along the course of the Snowy River as tributary flows enter the main channel, the impacts are still substantial in the lower Snowy River where the discharge represents 65% of MANF (Brooks *et al.* 2007). The diversion of water has lead to dramatic reductions in base flows, the magnitude, duration and frequency of floods and the complete loss of seasonal flow variability (Brooks *et al.* 2007). These hydrological changes have negatively affected flow related life-history cues, habitats and biota upon which fish are dependent and thus altering the distribution and abundance of native fish in the Snowy River system (Brown 1996).

In 2000, the New South Wales, Victorian, and Australian governments committed to the release of environmental water to rehabilitate the Snowy River (DNR 2007). The environmental water releases to the Snowy River are dependent on securing water savings in the Murray and Murrumbidgee river valleys. The environmental water releases were planned to be released via four stages, with a first increment to 6% MANF achieved by decommissioning the Mowamba River Aqueduct in 2002. Environmental water releases would then increase up to 15% MANF (142 GL $year^{-1}$) between years 2003 and 2008, and up to 21% MANF (212 GL $year^{-1}$) by 2011 following installation of a higher capacity outlet at Jindabyne Dam. Environmental water releases of up to 28% MANF may be delivered after 2011 dependent on further water savings in the Murray and Murrumbidgee river valleys.

Although several projects are currently underway in Australia to determine the responses of fish to different flow regimes and to understand the mechanisms involved in those responses (Humphries and Lake 2000; Chessman and Jones 2001; Chessman 2003), so far, little information has been documented on the response of Australian fish assemblages to provision of environmental flows (King *et al.* 2003). The responses achieved and the time scale over which they occur are likely to be influenced by the initial condition of the affected assemblages, the availability of nearby populations to seed recovery through dispersal, the magnitude and quality of the environmental flow regime implemented and the presence of other limiting factors, such as catchment degradation, absence of riparian vegetation and sedimentation of deep holes which may impede recovery of fish assemblages despite provision of increased flows. The potential outcomes of more natural flow conditions on fish populations include provision of spawning triggers, improved conditions for recruitment, greater habitat diversity supporting increased species richness and increased fish passage of native fish, with a simultaneous decline in those alien species such as goldfish and eastern gambusia that favour low flow environments (Brown 1996). Although, there may also be a concurrent increase in trout numbers which may have detrimental effects on populations of native fish (e.g. Fletcher 1979; Jackson and Williams 1980; Koehn and O'Connor 1990; Ault and White 1994, Jackson *et al.* 2004), partly negating potential ecological benefits arising from environmental water releases.

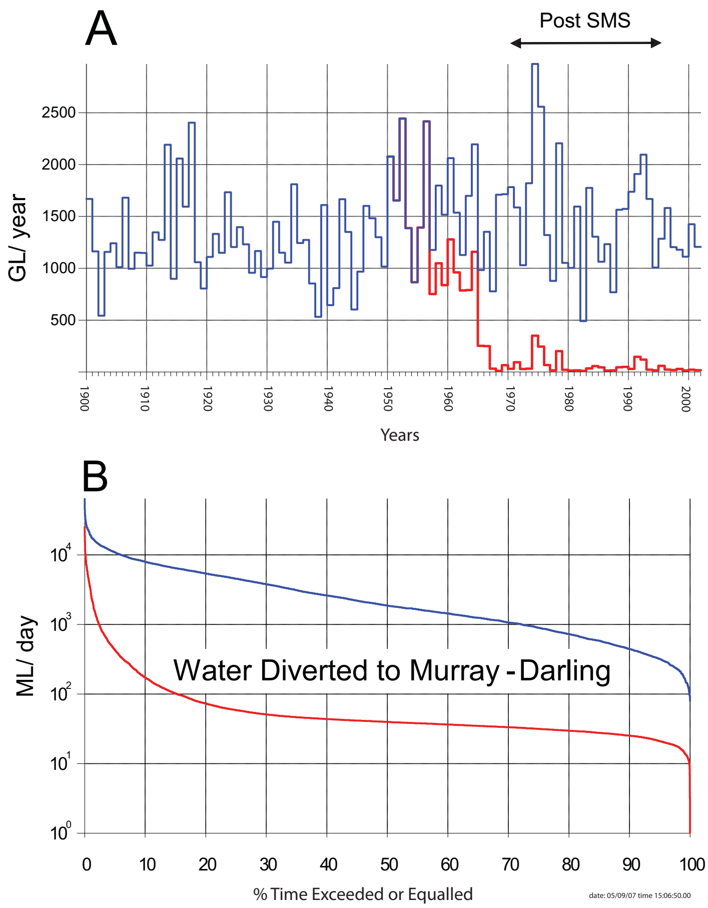


Figure 1. Hydrological Impact of the Snowy Mountains Scheme as measured at the Snowy River at Dalgety: (A) total annual discharge (GL) and (B) flow duration statistics, Pre SMS (Blue) and Post SMS (Red). Source Morton et al (in prep).

The Snowy River Flow Response Monitoring program assesses the response of key river attributes including river discharge, water quality, instream habitats, plants, water bugs and fish. The objectives of the fish component of the program are to:

1. Determine the changes in species richness, relative abundance and population size structure (range of body sizes) of fish assemblages following the introduction of 21 % MANF environmental flows.

2. Determine longitudinal patterns in the above following the introduction of 21 % MANF environmental flows.

To test for progress towards these objectives, four hypotheses were developed:

H_1 Fish assemblages will show increased species richness and abundance of native species, and expanded population size structures for native species compared to the pre-flow release period, following an increase in size and magnitude of floods, base flow and flow variability.

H_2 Native fish and trout abundance will increase upstream of Snowy Falls compared to the pre-flow release period because of increased habitat and recruitment following an increase in the size and magnitude of floods, base flow and flow variability.

H_3 The abundance (catch per unit standardised electrofishing sample) of alien species will decrease in the Snowy River (with the exception of trout) compared to the pre-flow release period, following an increase in base flow, flow variability and flushing flows.

H_4 As flows increase and water temperature decreases, alien species favouring slow warm water such as Eastern gambusia and goldfish will be reduced in abundance in the Snowy River while native fish species will increase in abundance compared to the pre-flow release period.

Each hypothesis specifies detection of a response only after the release of 21% MANF.

This report presents the results of the initial data collected to define the condition of fish assemblages in both the main channel of the Snowy River (test sites) and unregulated tributary streams (reference sites) before (2000-2002) and after (2003-2005) the implementation of the first stage of environmental water releases.

The first environmental releases occurred following closure of the Mowamba River Aqueduct on 28 August 2002 (Figure 2), which raised flows in the Snowy River at Dalgety from 1.9% MANF in 1998-2002 to 3.4 % MANF in 2002-2005 (Morton and Green, in prep). The median daily flows increased in the upland macro-reach (as measured at Dalgety) from 42.5 ML d^{-1} to 78.6 ML d^{-1} (Figure 3) (Brooks *et al.* 2007). However, daily variability increased slightly and a more natural pattern of seasonality (higher spring flows) occurred following de-regulation of the Mowamba River (Brooks *et al.* 2007). In the mid and lower catchment, despite the provision of environmental flows from the Mowamba River, the median daily flows were only 40% of the average regulated flows in both the reference and Snowy River sites, which reflects the drought conditions that persisted throughout the region during 2002-2005 (Brooks *et al*. 2007).

Figure 2. Changes in daily discharge (i) simulated natural (red) (ii) with the first stage environmental flow release (blue) and (iii) without the first stage environmental flow release (green) for the Snowy River at Dalgety, 2002-2005. Source: Morton et. al (in prep).

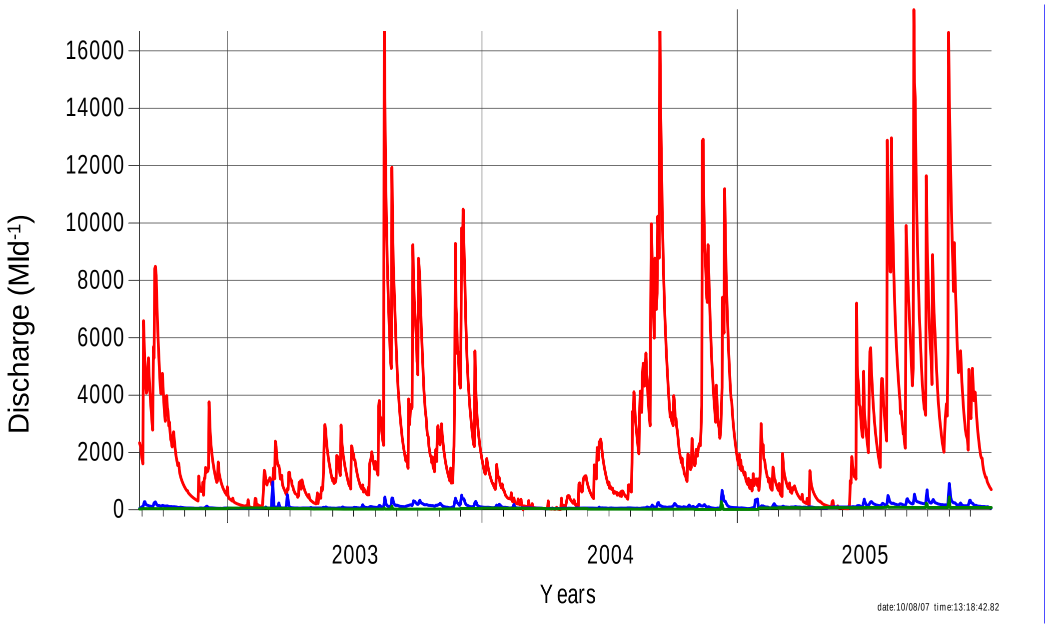
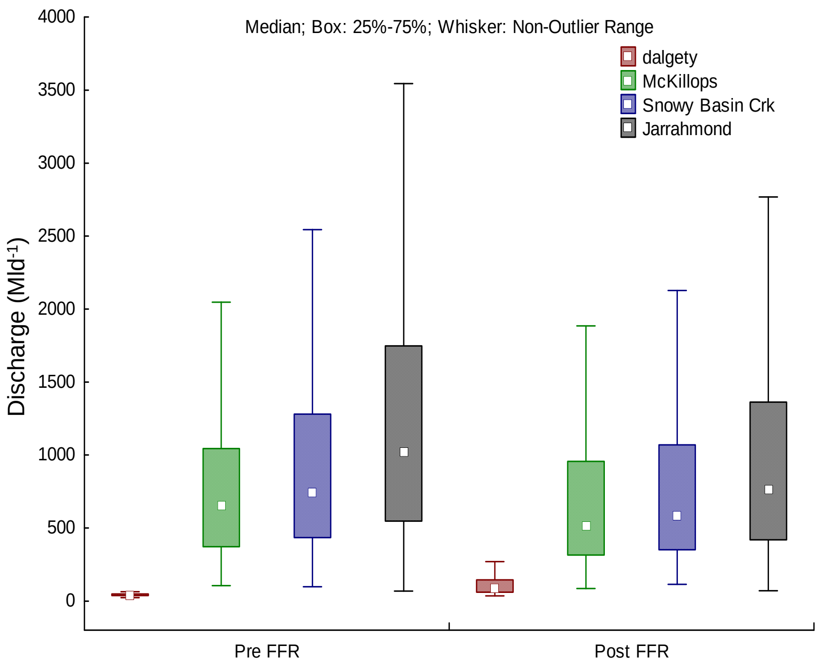


Figure 3. Daily discharge (25%, 50%, and 75%) at Snowy River gauging stations pre (2000-2002) - and post (2003-2005) the first environmental flow release. Source Brooks *et al.* (2007).



Further, wild bushfires occurred in the region in the summer of 2002-2003 (Appendix1), followed by a discharge event in March 2003 (mean daily discharge of 965 Mld^{-1}, and peak instantaneous discharge of 9,239 Mld^{-1} was recorded at Dalgety (Russell and Brooks, in prep.) prior to fish sampling in 2004 resulted in the run-off of silt, ash and charcoal (Rose and Henderson, 2005). Run-off following fire has been implicated in a number of fish kills and is likely to have had some impact on fish assemblages at affected sites monitored for this project (DSE 2006, DSE undated). Reference sites on the MacLaughlin River (Site 20 and 21), Delegate River (Sites 11 and 17) and Buchan River (Sites 15 and 19) were not affected by the fire. In contrast all sites in the Snowy River and the reference sites on the Deddick River received some ash-laden runoff. The potential impacts of these wild fires on fish include direct impacts such as poor water quality, including low dissolved oxygen, or indirect such as the loss of habitat that may lead to the loss of fish diversity and abundance. Thus, changes caused by the wild fire could result in rejection of the hypotheses, when in the absence of the wild fire they may not have been rejected. Therefore, the possible effect of wild fires on interpretation of environmental flow outcomes was also assessed.

2. Methods

2.1 STUDY AREA AND DESIGN

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 13,785km^2 (Figure 4). Four major natural barriers to fish movement have been identified in the Snowy River; these barriers are located in the upper reaches of the study area (Figure 4). The Snowy River at Snowy Falls was deemed to be the largest natural flow induced barrier to fish passage in the river system, and forms a key part of the sampling design. Sites above Snowy Fall are defined as the upper reaches and below Snowy Falls sites are defined as lower reaches for the fish monitoring program.

Fourteen of the 27 sites established for the ‘Snowy River Environmental Flow Response Monitoring’ were sampled for fish (Figure 4 and Table 1). These sites were stratified as either test sites or reference sites. Test sites occurred in the main channel of the Snowy River and are influenced directly by implementation of environmental water releases. Reference sites were located on major tributary streams of the Snowy River and have relatively natural flow regimes. Reference sites were required to separate the effects of environmental water releases from other catchment effects and to gauge the extent to which the Snowy River approaches a more ‘natural’ ecological condition.

Figure 4. Snowy River catchment showing the location of fish sampling sites (•) and major fish barriers (○).

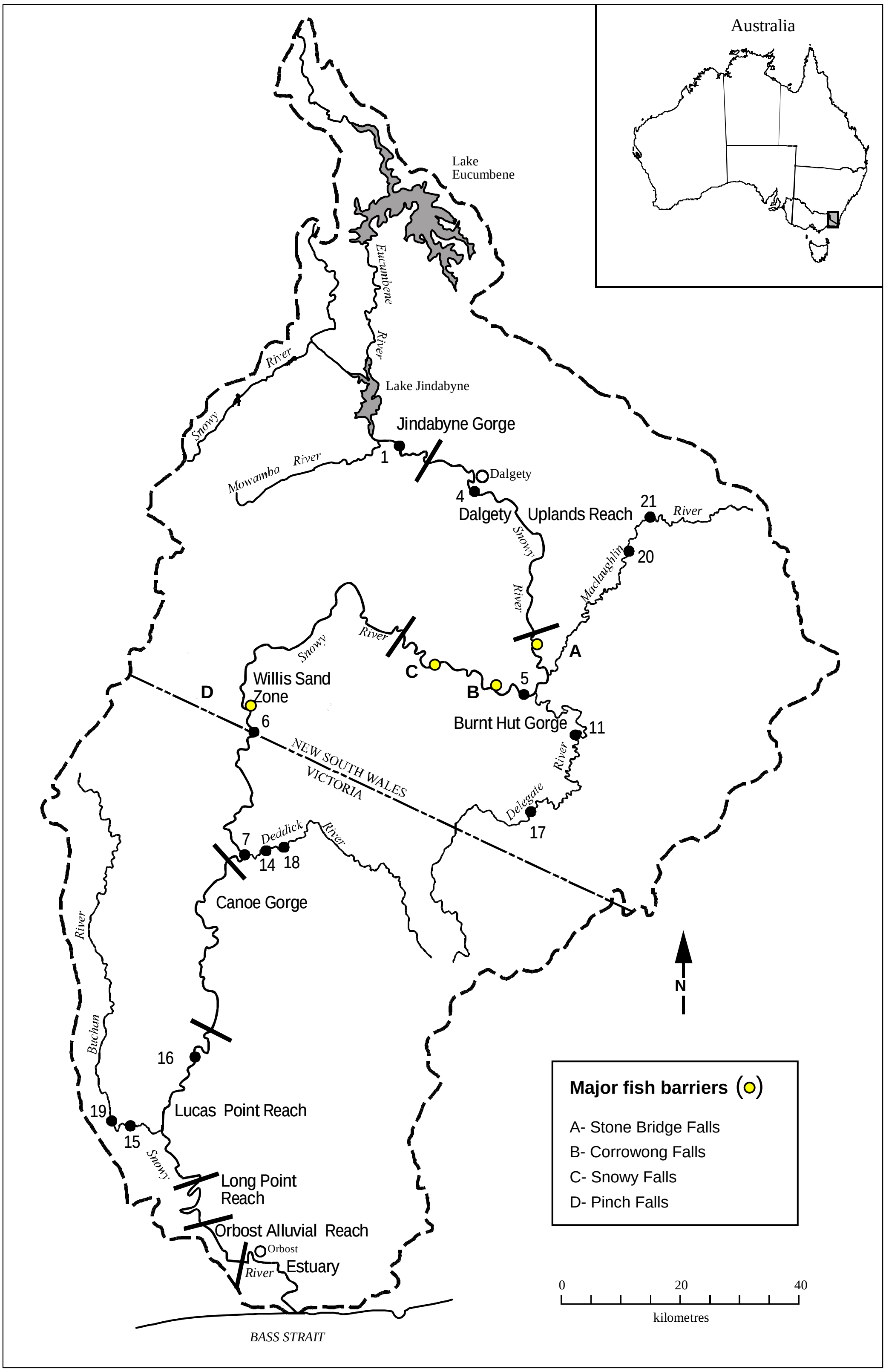


Table 1. Sampling sites for the broad-scale fish assessment of the Snowy River. Sites were stratified into those in the upper zone (those occurring upstream of Snowy Falls) and lower zone (those occurring downstream of Snowy Falls), and test and reference treatments. Reference* sites may be inappropriate for use as reference sites for fish due to the large proportion of diadromous fish present in the fish assemblage.

No.	Site name	Zone	Treatment	UTM Zone: 55	
				Easting	Northing
1	Snowy River downstream of Mowamba River	Upper	Test	6477	59650
4	Snowy River Downstream of Blackburn Creek	Upper	Test	6632	59567
5	Snowy River at Burnt Hut	Upper	Test	6724	59207
11	Delegate River at Quidong	Upper	Reference	6810	59136
17	Delegate River at Bill Jeffery's Park	Upper	Reference	6732	58987
20	MacLaughlin River at Sherwood	Upper	Reference	6894	59450
21	MacLaughlin River at Boco	Upper	Reference	6909	59490
6	Snowy River at Willis	Lower	Test	6268	59162
7	Snowy River at McKillop's Bridge	Lower	Test	6254	58948
16	Snowy River at Jackson's Crossing	Lower	Test	6179	58604
14	Deddick River at Deddick Park	Lower	Reference*	6278	58938
15	Buchan River at Buchan 2	Lower	Reference*	6086	58483
18	Deddick River at Ambyne	Lower	Reference*	6308	58958
19	Buchan River at Buchan Station	Lower	Reference*	6061	58487

2.2 SAMPLING

Sampling methods (Gehrke *et al.*, in prep) are based on those developed for the NSW Rivers Survey (Harris and Gehrke 1997). Fish assemblages were sampled in March 2000, February 2001, March 2002, March 2003, March 2004 and January 2005 by electrofishing. Where boat access was available, sampling was done using a small electrofishing vessel (3.6 metre, flat-bottomed aluminium electrofishing boat equipped with a 2.5 kW Smith-Root Model GPP 2.5 H/L). The boat has anodes suspended from the bow and cathodes mounted along the sides. The electrofishing unit was generally operated at between 500 and 1000 V DC, 4 to 8 amps pulsed at 120 Hz and 70-90% duty cycle, depending on water conductivity. One operator drives the boat and operates the electrofisher controls whilst a second operator nets immobilised fish from the water and places them in a live well to recover (Figure 5). Back-pack electrofishing was only undertaken when boat access was not possible or when the pool habitats were too shallow to launch or navigate the boat. Under these circumstances, pool and riffle habitats were sampled using a 400 W Smith-Root Model 12 backpack electrofisher. The pulsed DC output used in this study was generally between 400 and 600 V, 0.5 to 1.0 amp at 60 Hz. Fish were immobilised, collected by an assistant with a dip net, and placed in a bucket to recover. In some instances, a combination of both boat and backpack electrofishing was used.

Each electrofishing operation consisted of two minutes (elapsed time) of sampling. Fifteen replicate operations were attempted at each site, but if insufficient water was present to complete 15 operations, a minimum of eight operations was required. Sampling did not target any specific habitat types within the site and all habitats present were sampled in proportion to their occurrence.

Figure 5. Electrofishing at the Snowy River downstream of Blackburn Creek junction (Site 4) using FRV Pole Volt.

At the end of each two-minute operation, all fish were identified, counted, measured, inspected for any external parasite or disease, and released. Length measurements to the nearest millimetre were taken as fork length for species with forked tails, and total length for other species. Eels are difficult to handle without anaesthetic, and electrofished eels were identified in the water and their length is estimated rather than measured.

2.3 DATA ANALYSIS

Multivariate analyses were undertaken using PRIMER 5.2.9 (Plymouth Marine Laboratory) in order to:

1. compare fish assemblage structure in the lower (below Snowy Falls-Figure 6) and upper (above Snowy Falls) reaches of the catchment,
2. assess inter-year variability at sites in the three years prior to environmental flows,
3. assess the impact of the 2003 bushfires on fish assemblages, and
4. assess changes in test and reference sites after three years of release of 3% MANF

Figure 6. The Snowy River at Snowy Falls (UTM Zone 55: 655402.08E, 5927309.99N), a significant natural barrier to the upstream passage of diadromous fish. Source: Robyn Bevitt.

Similarity matrices were created using the Bray-Curtis similarity index (Bray and Curtis 1957) calculated on CPUE (catch-per-unit-effort) as fish per hour. Data were fourth root transformed to reduce differences in scale among species abundances but retain information on relative abundance. Data were plotted using both a hierarchical agglomerative classification analysis using the group-average linking algorithm and multi-dimensional scaling (MDS) ordinations in two dimensions. ANOSIM (ANalysis Of SIMilarities) (Clarke 1993) was used to test differences in fish assemblage structure across four sample categories within each of the upper and lower zones. Site categories were: test sites pre-flow release (2% MANF); test sites post-flow release (3% MANF); reference sites pre-flow release and reference sites post-flow release. This analysis was expanded by splitting the ‘post-flow release’ categories into fire impacted (sites which were fire-impacted in 2003) and non-fire impacted samples (un-impacted samples from 2003 + all samples from 2004 and 2005). Inter-year variability among the three years of pre-flow release data were analysed using a two-way nested ANOSIM2 analysis with years nested within sites and using Spearman rank correlations to assess consistency across sites (Clarke and Warwick 2001). Permutation tests to estimate the probability of the observed results used 5,000 randomisations. Where significant differences were identified, SIMPER (SIMilarity PERcentages) analyses were used to identify the species contributing most to dissimilarities (Clarke and Warwick 2001).

Univariate analyses were undertaken to test each hypothesis using the following variables:

Hypothesis 1: Native species richness (un-transformed) and proportion native individuals (arcsine transformed).

Hypothesis 2: Abundance of trout (brown trout (*Salmo trutta*)) – upper zone only ($\log_{10}(x+1)$ transformed).

Hypothesis 3: Proportion of pest (goldfish (*Carassius auratus*), eastern gambusia (*Gambusia holbrooki*) and redfin perch (*Perca fluviatilis*)) individuals (arcsine transformed).

Hypothesis 4: Abundance of individual species (all species $\log_{10}(x+1)$ transformed).

Variables required to test hypotheses were checked for normality using QQ plots in S-Plus 6.1 and homogeneity of variance using F_{max}-tests (Sokal and Rohlf 1995). Transformation used to normalise data and equalise variances are indicated below. Despite the $\log_{10}(x+1)$ transformation, data for many individual species was not normalised due to the abundance of 0's. Elimination of this problem is not possible through the use of non-parametric analyses. Further, as the test for an interaction between before v after and test v reference samples was a particularly important component of the analysis, parametric tests are required. However given the non-normal distributions of the data for most species, results should be interpreted with caution.

The sampling frame is structured by catchment zone (upper and lower) and location (main channel (test) and tributary (reference)) with each site sampled for six years (2000-2005). There were two flow treatments: pre (2000-2002) and post (2003-2005) environmental releases. Sampling structure was fitted as random effects, treatment was fitted as fixed effect. As each flow treatment was applied for three consecutive years the flow treatment is confounded with year. An analysis of variance decomposition is given in Table 2. All variables were estimated using the residual maximum likelihood (REML) technique. The analysis was conducted using the statistical software package ASReml (Gilmour *et al.* 2006).

Due to the binomial nature of the data for the variables; proportion of native fish and proportion of pest fish, a generalised linear mixed model using a logit link function was fitted using penalised quasi-likelihood (PQL) and had the following ASReml syntax:

```
native_count !BIN !LOGIT !TOTAL total_counted ~ mu flow

!r site zone location zone.location year zone.flow flow.location flow.zone.location,
site.flow zone.year location.year zone.location.year
```

The count data for individual species were analysed using a Poisson distribution with a generalized linear mixed model using a natural logarithmic link function using penalised quasi-likelihood (PQL) which had the following ASReml syntax:

```
species_count !POISSON ~ mu flow

!r site zone location zone.location year zone.flow flow.location flow.zone.location,
site.flow zone.year location.year zone.location.year
```

However, some species were found in only the upper or lower zone. To reduce the number of zeros in the analyses, a modified model (removing zone and any interactions which included zone) was fitted to only the data from the zone where the species was present. Table 3 shows the zone/s in which each species was found. Despite fitting a Poisson distribution to the individual species count data, many species still did not meet all model assumptions due to the abundance of zeros, so the results should be interpreted with caution.

Table 2. Analysis of Variance Decomposition.

Model			Degrees of freedom*	Fixed or Random
Site			14	
		Mean	1	F
		Zone	1	R
		Location	1	R
		Zone.location	1	R
		Residual	10	R
Site.Year			70	
	Year		5	
		Flow	1	F
		Residual year	4	R
	Zone.year		5	
		Zone.flow	1	R
		Residual zone.year	4	R
	Location.year		5	
		Location.flow	1	R
		Residual location.year	4	R
	Zone.location.year		5	
		Zone.location.flow	1	R
		Residual zone.location.year	4	R
	Site.flow		10	R
	Residual		40	R
Total			84	

* provided as a guide only, actual degrees of freedom will vary when Kenward adjustment is applied to unbalanced data.

Table 3. The distribution of individual fish species in the upper and lower zones of the Snowy River system and the application of modified models to account for the zero observations.

Species	Common name	Upper Zone	Lower Zone
Anguilla australis	Short finned eel	*	*
Anguilla reinhardtii	Long finned eel	*	*
Retropinna semoni	Australian smelt	*	*
Carassius auratus	Goldfish#	*	*
Gambusia holbrooki	Eastern gambusia#	*	*
Salmo trutta	Brown trout#	*	
Gadopsis marmoratus	River blackfish	*	
Galaxias olidus	Mountain galaxias	*	
Perca fluviatilis	Redfin perch#	*	
Galaxias maculatus	Common galaxias		*
Gobiomorphus australis	Striped gudgeon		*
Mordacia spp.	Lamprey spp.		*
Nannoperca australis	Southern pygmy perch		*
Pseudaphritis urvillii	Congoli		*
Macquarie novemaculeata	Australian bass		*

introduced taxa

Abundance of the following species were not analysed as there were insufficient observations: Cox's gudgeon (*Gobiomorphus coxii*), Flat-headed gudgeon (*Philypnodon grandiceps*) and Australian grayling (*Prototroctes mareana*).

Analysis of length-frequency distributions requires large sample sizes in order to adequately reflect the distribution of the population. A minimum sample size of n = 30 was required in order to compare groups. The only species with sufficient sample sizes are listed in Table 4.

Table 4. Fish considered for analysis of length-frequency distribution for the Snowy River catchment, 2002-2005.

Fish species	Upper		Lower	
	Test	Ref	Test	Ref
Short-finned eel (*Anguilla australis*)	•	•		
Goldfish (*Carassius auratus*)	•			
Mountain galaxias (*Galaxias olidus*)		•		
Brown trout (*Salmo trutta*)		•		
Eastern gambusia (*Gambusia holbrooki*)			•	
Congoli (*Pseudaphritis urvilli*)			•	•
Australian smelt (*Retropinna semoni*)			•	•
Long-finned eel (*Anguilla reinhardtii*)			•	•

Length-frequency distributions were compared using Kolmogorov-Smirnov tests in S-Plus 6.1. For those populations where significant differences were detected, three additional variables were calculated: mean and standard deviation of length, the size range (length of the largest individual minus the length of the smallest individual) and the coefficient of variation of length.

3. Results

3.1 MULTIVARIATE FISH ASSEMBLAGE ANALYSES

The three pre-flow release samples collected before August 2002 adequately characterised the fish assemblage of the Snowy River catchment at that time. A distinct dichotomy was observed with the fish assemblage in the upper parts of the catchment (above Snowy Falls) being significantly different from the fish assemblage that existed below Snowy Falls (ANOSIM Global $R = 0.692$, $p = 0.001$) (Figure 7). The two zones were distinguished by the greater abundance of Australian smelt and long-finned eel below Snowy Falls, the absence of congoli above Snowy Falls and a greater abundance of short-finned eel in the upper parts of the catchment (Table 5). These four species contributed 60% of the dissimilarity between upper and lower zones with the average Bray-Curtis similarity of sites between each zone being 18%. Fish assemblages in the upper catchment were quite variable across sites, with an average similarity of 37%, whilst fish assemblages in the lower catchment sites were more consistent with an average similarity of 54% (Figure 8).

Although not as great as the differences observed between sites in the upper and lower zones, there were significant differences between fish assemblages in reference and test sites in both upper ($R = 0.466$, $p = 0.001$) and lower ($R = 0.324$, $p = 0.005$) parts of the Snowy River catchment. Test and reference sites in the upper catchment had an average similarity of 39% while those in the lower zone were much more similar with an average similarity of 58%.

Test sites within the upper zone had an average similarity of 35% and were characterised by the presence of goldfish and a greater abundance of long-finned eel (Table 6). Reference sites in the upper zone were more consistent (average similarity of 54%) and were characterised by an absence of goldfish and a greater abundance of short-finned eel and brown trout than test sites (Table 6).

In the lower zone, test sites had an average similarity of 59% and were characterised by the presence of eastern gambusia, much greater abundance of long-finned eel and a slightly higher abundance of Australian smelt, short-finned eel and congoli (Table 7). The lower catchment reference sites were the most consistent of any of the four groups with an average similarity of 69%. The fish assemblage at these sites contained a slightly greater abundance of common galaxias and short-headed lamprey. Eastern gambusia were not detected in the lowland tributaries (Table 7).

There was no significant inter-year variability within sites for the pre-flow release samples collected between 2000 and 2002 (ANOSIM2 Global $R = 0.011$, $p = 0.341$).

Figure 7. Classification analysis of sites in the Snowy River catchment based on Bray-Curtis similarities of fish assemblage samples collected before (2000–2001: 2% MANF) or after (2003-2005: 3% MANF) implementation of the first increment of environmental flows. Samples shaded yellow were in the upper part of the catchment above Snowy Falls and samples shaded blue were in the lower part of the catchment below Snowy Falls.

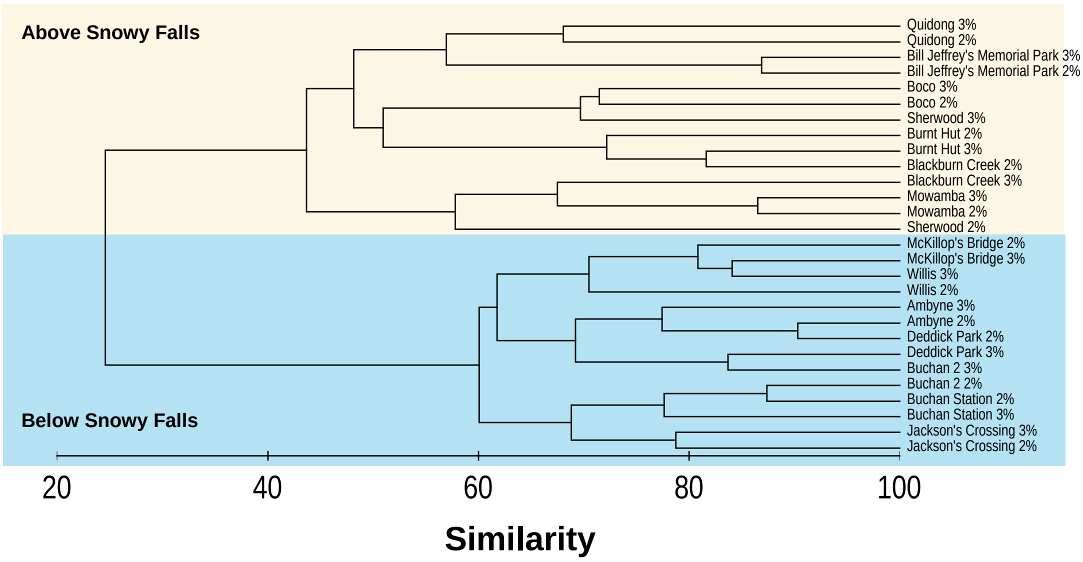


Figure 8. MDS ordination of samples grouped into four categories: 2% Reference – (reference sites sampled before the first flow release), 3% Reference – (reference sites sampled after the first flow release), 2% Test – (test sites sampled before flows) and 3% Test – (test sites sampled after flows). Each point represents an individual sampling occasion. Lower catchment sites (below Snowy falls) are enclosed by the black ellipse.

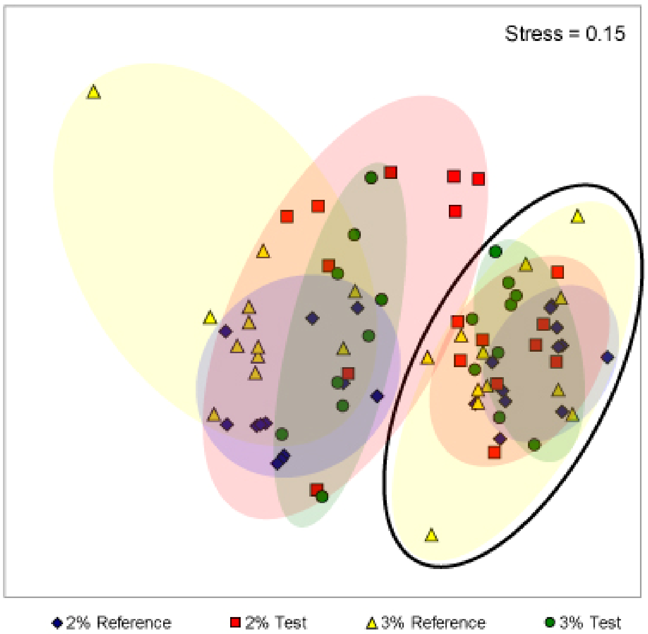


Table 5. Contributions of species to the dissimilarity between fish assemblages in the upper part (above Snowy Falls) and lower part (below Snowy Falls) of the Snowy River catchment. The consistency ratio (δ_i/SD(δ_i): Clarke and Warwick 2001) indicates the consistency with which each species discriminates between zones, with larger values indicating greater consistency. The cumulative % column indicates the cumulative contribution of each species to the average dissimilarity between zones. The average dissimilarity (D%) is expressed as a percentage ranging from 0 (identical) to 100 (totally dissimilar).

Species	**Mean abundance (catch per hour of electrofishing)**		**Consistency ratio**	**Cumulative%**	**D%**
Before environmental flows	Upper	Lower			81.12
Australian smelt	0.02	13.83	1.57	18.58	
Congoli	0.00	3.80	1.93	34.29	
Short-finned eel	4.80	0.54	1.17	47.74	
Long-finned eel	1.91	2.95	1.57	60.28	
After environmental flows	Upper	Lower			79.58
Australian smelt	0.00	19.72	1.56	16.32	
Short-finned eel	4.53	0.81	1.09	28.51	
Congoli	0.00	3.54	1.58	39.54	
Long-finned eel	0.50	3.48	1.44	50.87	

Table 6. Contributions of species to the dissimilarity between fish assemblages of reference and test sites in the upper catchment zones before and after implementation of environmental flows. The consistency ratio (δ_i/SD(δ_i): Clarke and Warwick 2001) indicates the consistency with which each species discriminates between groups of sites, with larger values indicating greater consistency. The cumulative % column indicates the cumulative contribution of each species to the average dissimilarity between groups. The average dissimilarity (D%) is expressed as a percentage ranging from 0 (identical) to 100 (totally dissimilar).

Species	**Mean abundance (catch per hour of electrofishing)**		**Consistency ratio**	**Cumulative %**	**D%**
Before environmental flows	Reference	Test			71.21
Goldfish	0.00	4.39	1.18	19.69	
Short-finned eel	5.26	2.84	1.38	39.06	
Long-finned eel	0.28	3.67	1.16	57.71	
Brown trout	1.43	0.83	1.15	70.78	
After environmental flows	Reference	Test			62.73
Mountain galaxias	14.21	2.06	1.30	18.76	
Goldfish	0.04	6.28	1.03	34.93	
Brown trout	1.86	0.89	1.10	48.81	
Long-finned eel	0.17	1.00	1.47	62.59	

Table 7. Contributions of species to the dissimilarity between fish assemblages of reference and test sites in the lower catchment zones before and after implementation of environmental flows. The consistency ratio indicates the consistency with which each species discriminates between groups of sites, with larger values indicating greater consistency. The cumulative % column indicates the cumulative contribution of each species to the average dissimilarity between groups. The average dissimilarity (D%) is expressed as a percentage ranging from 0 (identical) to 100 (totally dissimilar).

Species	Mean abundance (catch per hour of electrofishing)		Consistency ratio	Cumulative %	D%
Before environmental flows	Reference	Test			41.57
Australian smelt	15.02	16.86	1.02	17.80	
Common galaxias	1.73	0.77	1.05	28.32	
Short-finned eel	0.33	0.76	1.11	39.55	
Long-finned eel	1.02	6.28	1.24	49.68	
Congoli	3.01	6.13	1.56	56.30	
After environmental flows	Reference	Test			50.42
Australian smelt	7.69	42.33	1.20	17.23	
Goldfish	0.04	3.28	1.94	22.40	
Eastern gambusia	0.00	14.11	1.13	48.88	
Congoli	2.57	6.00	1.19	59.21	
Common galaxias	1.55	1.89	1.06	68.79	
Short finned eel	1.07	0.39	1.10	77.22	
Long-finned eel	2.13	6.22	1.11	84.51	

3.2 ASSESSING THE FIRST STAGE OF ENVIRONMENTAL FLOW IMPLEMENTATION

Following three years of environmental flow release, the fish assemblages of the upper and lower zones were still significantly different (ANOSIM Global R = 0.662, p = 0.001). However, fish assemblages in upper catchment sites show slightly less variability, with the average similarity increasing by 9.9% to 47% whilst variability between sites in the lowland zone increased by 8.7% to 45%. The post-release differences between zones were driven by the same four species (Table 4). The average similarity of sites between upper and lower zones increased by only 1.5% to 20%. Contrary to expectations, the fish assemblage at references sites in the upper zone changed significantly (R = 0.158, p = 0.016), due to increases in the abundance of both mountain galaxias and brown trout. The fish assemblage at test sites did not change significantly as was expected given the minimal increase in flows (R = 0.05, p = 0.204).

In contrast to the upper zone, fish assemblages in the lower catchment reference sites did not change significantly following environmental flows (R = 0.074 , p = 0.079). Similarly, no significant change was detected at test sites in the lower catchment (R = 0.074, p = 0.154).

Although reference and test sites in the upper zone were still significantly different following implementation of environmental flows (R = 0.334, p = 0.001), the average similarity between reference and test sites had increased from 28% to 37%, indicating that the fish assemblages of the test sites and reference sites were becoming more similar.

Fish assemblages of test and reference sites in the lower catchment were still significantly different (R = 0.300, p = 0.001). However, in contrast to the upper zone results test and reference sites in the lower zone had become more divergent, with the average similarity between sites in each zone decreasing from 58% to 49%.

3.3 TESTING PROJECT HYPOTHESES

Hypothesis 1: Increased species richness and relative abundance of native species, and expanded population size structure

Native species richness did not change significantly ($F_{1,9}$ = 0.23, p = 0.641) following implementation of environmental flows (Figure 6). The location (reference sites versus test sites) or flow x location interaction did not explain any of the variation (0% random variation explained), indicating that the provision of environmental flows has had no effect of fish assemblages.

There were no significant changes in the proportion of individuals that were native fish following implementation of environmental flows ($F_{1,1.8}$ = 0.39, p = 0.597). However the location (reference sites versus test sites) contributed to the explanation of variation (31% random variation explained) indicating there was a higher proportion of native individuals at reference sites (Figure 7). There was no effect of the flow x location interaction (0% random variation explained) suggesting little response to provision of environmental flows.

Of the 12 comparisons where sufficient sample sizes enabled statistical tests, seven showed significant changes in size-frequency distributions before and after implementation of environmental flows, however, few of the changes were profound (Figures 8 and 9).

In the upper zone, the length-frequency distributions changed for reference site populations of mountain galaxias (p = 0.003) and brown trout (p <0.001). The mean size of mountain galaxias declined from 47 mm to 44 mm following the implementation of flows. The size range of mountain galaxias was similar before and after the environmental water releases but the coefficient of variation decreased from 13.28 to 9.12 (Figure 8). In contrast, the mean size of brown trout increased from 200 mm to 218 mm, the range in sizes declined by 184 mm and the coefficient of variation decreased from 83.70 to 39.44 (Figure 8). The length-frequency distributions of goldfish at test sites and short-finned eel at test and reference sites did not change significantly (Figure 8).

In the lower zone, the length-frequency distributions changed for test site populations of Australian smelt (p = 0.001), congoli (p = 0.027) and eastern gambusia (p = 0.003) and reference site populations of Australian smelt (p = 0.002) and congoli (p = 0.006). The mean size of Australian smelt at test sites increased from 40mm to 44 mm, the size range increased by 27mm and the coefficient of variation increased from 8.93 to 21.55 (Figure 9). Similarly, Australian smelt populations at reference sites increased in mean size from 46 mm to 51 mm and the coefficient of variation increased from 3.97 to 23.99 but the size range did not change (Figure 9). The mean size of congoli at test sites decreased from 129 mm to 109 mm, the size range decreased by 23 mm and the coefficient of variation decreased from

43.56 to 35.01 (Figure 9). Congoli populations in the reference sites also decreased in mean size, from 140 mm to 118 mm, size range decreased by 37 mm but the coefficient of variation remained steady at 41.14 and 40.06 over the time periods co-incident with the delivery of environmental zones at test sites (Figure 9). Lastly, the mean size of eastern gambusia at test sites decreased from 37 mm to 28 mm but the size range increased by 54 mm. The coefficient of variation in size for eastern gambusia decreased from 117.29 to 24.14 (Figure 9). The length-frequency distribution of long-finned eel at test sites and reference sites did not change (Figure 9).

Figure 9. Average (± SE) number of native fish species at reference sites and test sites, before (2% MANF) and after (3% MANF) implementation of environmental flows in the upper and lower catchment zones.

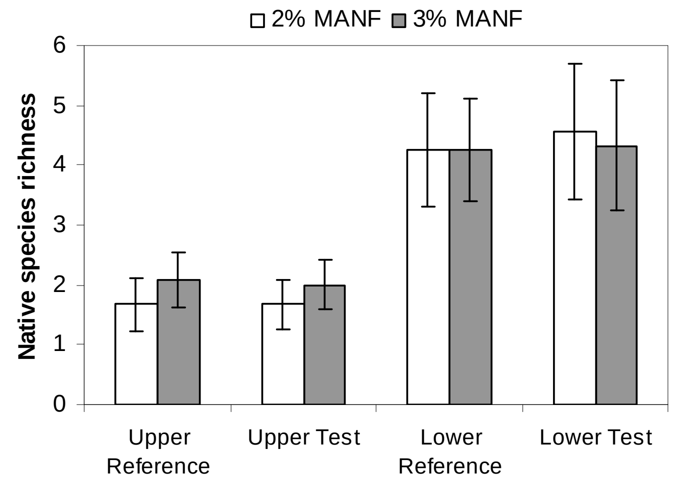


Figure 10. Average (± SE) proportion of individuals sampled that were native fish species at reference sites and test sites, before (2% MANF) and after (3% MANF) implementation of environmental flows in the upper and lower catchment zones.

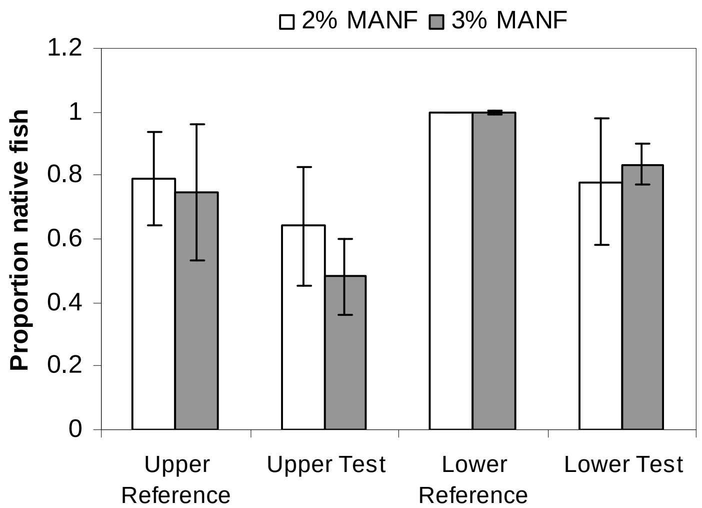


Figure 11. Length-frequency distributions for species in the upper Snowy River catchment (above Snowy Falls) before and after implementation of environmental flows. Population size structures are presented separately for reference and test sites. p values represent the significance of two sample Kolmogorov-Smirnov goodness-of-fit tests with p < 0.05 indicating significant differences in size frequency distributions before and after implementation of environmental flows.

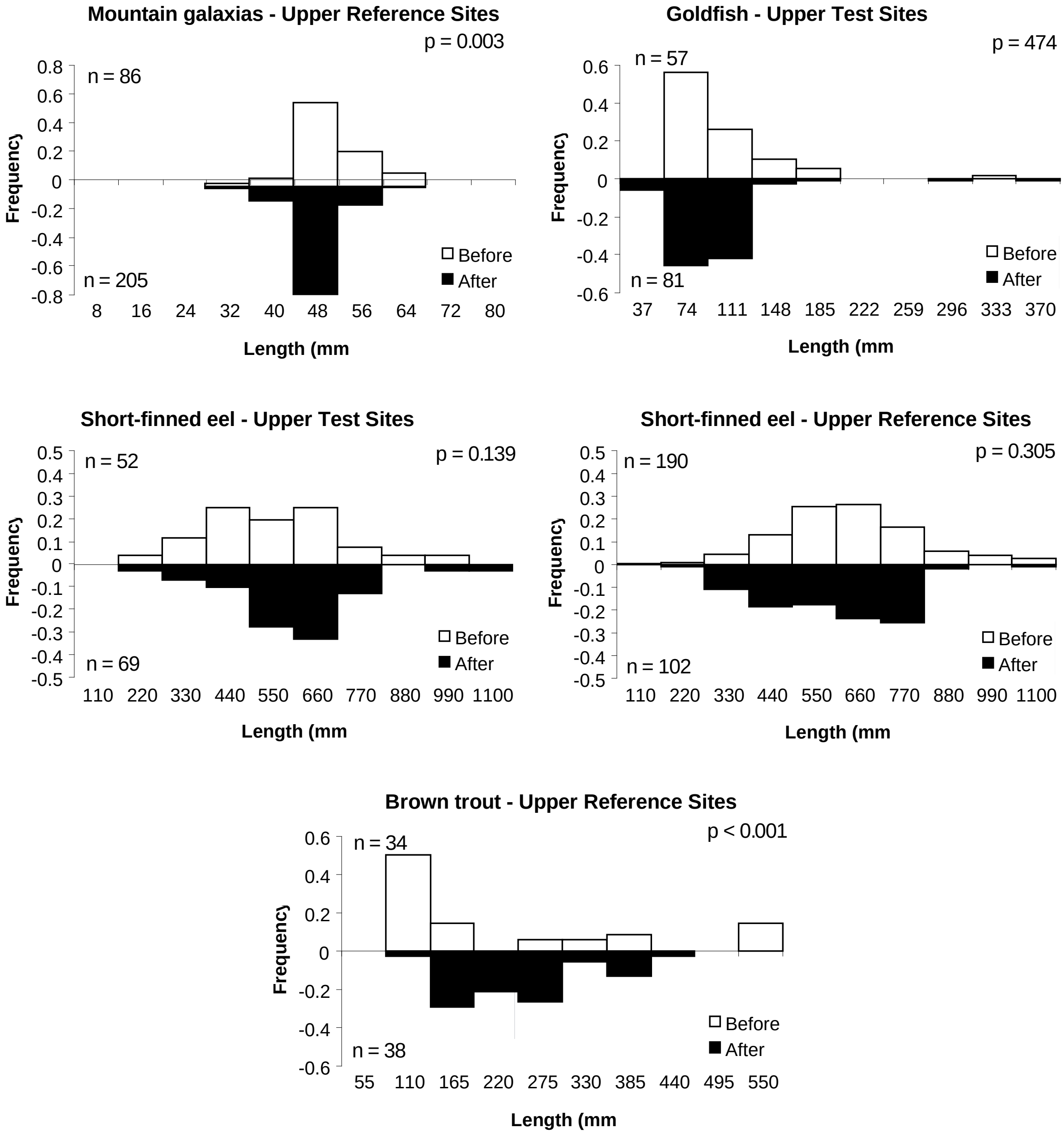
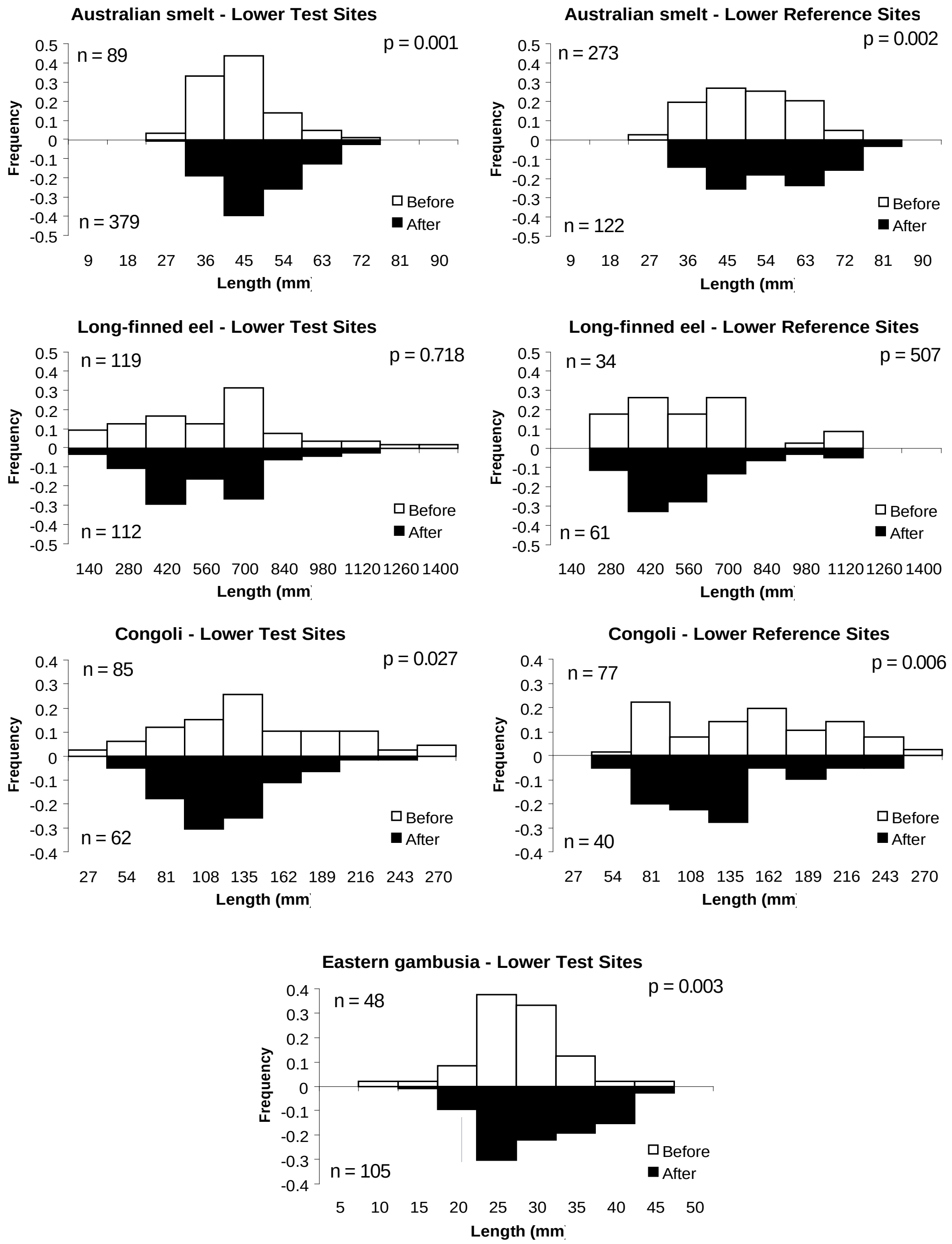


Figure 12. Length-frequency distributions for species in the lower Snowy River catchment (below Snowy Falls) before and after implementation of environmental flows. Population size structures are presented separately for reference and test sites. *p* values represent the significance of two sample Kolmogorov-Smirnov goodness-of-fit tests with *p* < 0.05 indicating significant differences in size frequency distributions before and after implementation of environmental flows.



Hypothesis 2: Increase in the abundance of trout in the upper zone.

There was no significant change in the abundance of trout in the upper zone following implementation of environmental flows ($F_{1,4.2} = 0.19$, $p = 0.685$) (Figure 10). The location (reference sites versus test sites) or flow x location interaction did not explain any of the variation (0% random variation explained), indicating that the provision of environmental flows has had no effect of fish assemblages.

Hypothesis 3: Decrease in the abundance of pest species other than trout (goldfish, eastern gambusia and redfin perch).

The proportion of pest fish was greater at test sites than at reference sites (54.60% random variation explained) (Figure 11). However there were no significant changes following implementation of environmental flows ($F_{1,5.3} = 1.69$, $p = 0.250$) and there was no effect of the flow x location interaction (0% random variation explained).

Hypothesis 4: Alien species favouring slow warm water (gambusia and goldfish) will decline while native species will increase in abundance.

No species (of the 15 analysed) exhibited a significant response to an increase from 2% MANF to 3% MANF.

Five species were found in the upper and lower catchment with the abundance of three species being greater at test sites; long-finned eel (44.49% random variation explained), goldfish (78.49% random variation explained) and Eastern gambusia (80.43% random variation explained) (Figure 12). There was no effect of the flow x location interaction (0-2.68% random variation explained).

Of the four species found only in the upper catchment, River blackfish (*Gadopsis marmoratus*) was the only species with a difference in abundance between reference and test sites (42.49% random variation explained), being more abundant at reference sites (Figure 12). However, there was no effect of the flow x location interaction (0% random variation explained).

Of the six species found only in the lower catchment, congoli was the only species with a difference in abundance between test and reference sites (21.74% random variation explained), being more abundant at test sites (Figure 12). The only species to exhibit an important flow x location interaction was Southern pygmy perch (*Nannoperca australis*) where 37.98% of random variation was explained by the interaction term. The abundance of Southern pygmy perch declined at reference sites but increased at test sites.

Figure 13. Average (± SE) catch per hour of electrofishing (CPUE) of Brown trout at reference sites and test sites, before (2% MANF) and after (3% MANF) implementation of environmental flows in the upper and lower catchment zones.

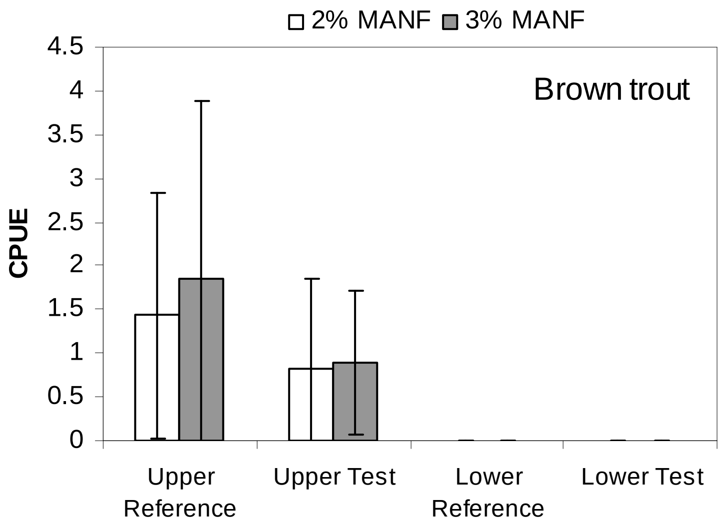


Figure 14. Average (± SE) proportion of individuals sampled that were pest species (goldfish, gambusia and redfin perch) at reference sites and test sites, before (2% MANF) and after (3% MANF) implementation of environmental flows in the upper and lower catchment zones.

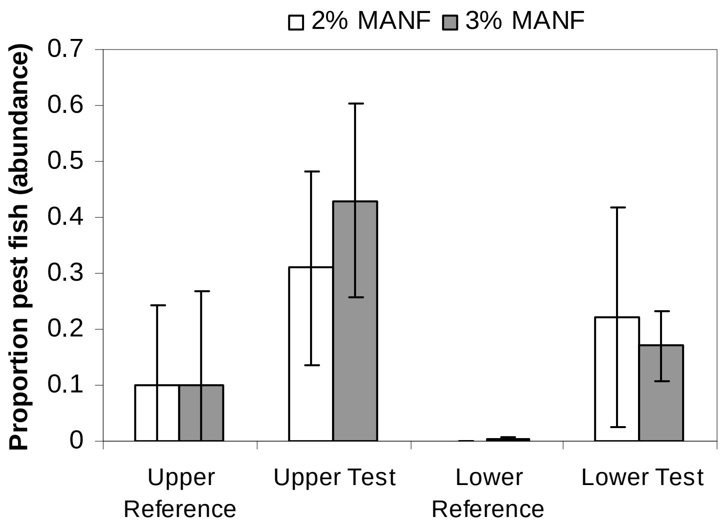
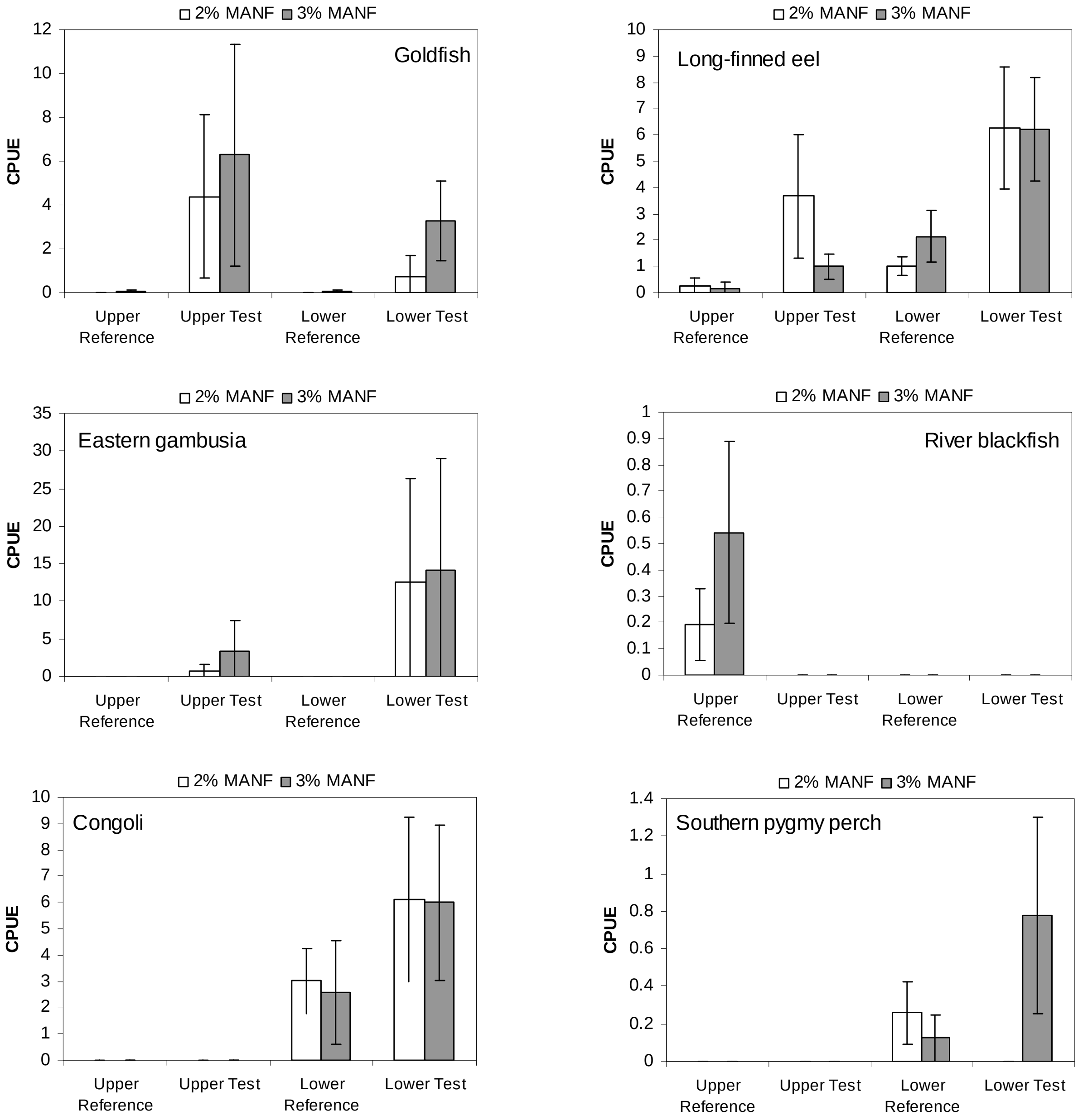


Figure 15. Average (± SE) catch per hour of electrofishing (CPUE) per site for those species which showed significant differences in abundance between reference and test sites, before (2% MANF) and after (3% MANF) implementation of environmental flows or interactions between flow and treatment in either the upper or lower catchment zones



3.4 FIRE IMPACTS

Wild bushfires followed by heavy rainfall immediately preceding fish sampling in 2003 had the potential to obscure the positive outcomes resulting from the first year of environmental flows.

Within the upper catchment zone, no reference sites were fire affected. This situation could result in a reduced recovery or even a decline in fish assemblages in the test sites despite provision of environmental flows. Although all test sites were affected, post fire run-off did not significantly alter the fish assemblage compared to that which was sampled in the preceding three years (R = -0.519, p = 1.00) and there were no differences between the fish assemblage sampled at test sites during the run-off event or that which existed in the following two years (R = -0.704, p = 1.00), all of which had increased environmental flows. Lastly, there were no significant changes at test sites between the pre-flow release samples and those collected in the 2^{nd} and 3^{rd} year of post-flow sampling which were not fire affected (R = -0.370, p = 0.90). As all test and some (but not all) reference sites in the lower zone were fire affected, the results from this part of the catchment are more complex. As in the upper zone, test sites in the lower zone did not change significantly from pre-flow conditions in either the fire year (R = -0.222, p = 0.900) or the two post-fire years (R = -0.556, p = 1.000) and fish assemblages at fire affected reference sites did not change from the pre-flow conditions in both 2003 (R = -0.25, p = 1.00) and in 2004/05 (R = 0.000, p = 0.667) and there were no changes between 2003 and 2004/05 (R = -0.500, p = 1.000).

These results suggest that the bushfire affected run-off present during sampling in 2003 did not result in a decline in fish populations. Further, the comparison of 2003 with 2004/05 data suggest that unless the impacts persisted across all three post-flow sampling years, there is no evidence to indicate that the fire impacts masked any potential response arising from the release of environmental flows at test sites in 2003.

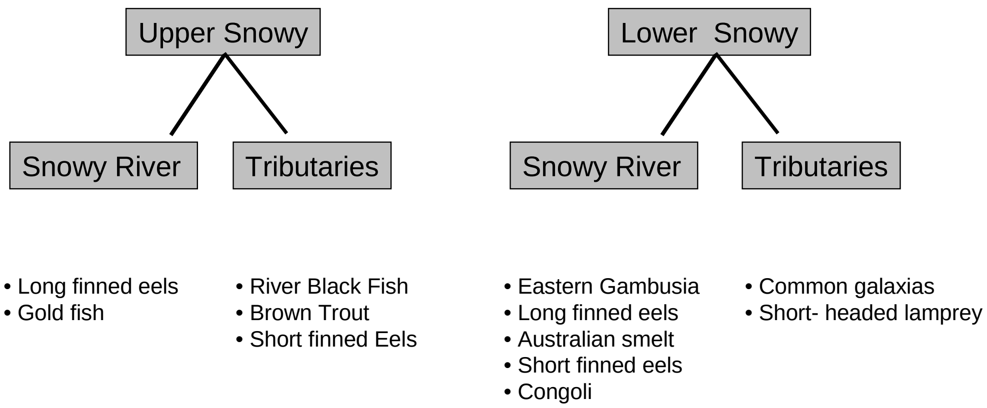
4. Discussion

4.1 FISH ASSEMBLAGES AND THE ASSESSMENT OF THE FIRST RELEASE

Fish assemblages of the Snowy River

Prior to the first environmental water release in 2002, the broad-scale fish assemblages of the freshwater reaches of the Snowy River catchment was clearly divided into two main groups; an upper catchment fish assemblage occurring upstream of major natural barriers such as Snowy Falls, and a lower catchment fish assemblage occurring downstream (Figure 16). Within these two main sample groupings a secondary grouping exists that being the highly regulated main channel of the Snowy River (test sites) and the un-regulated tributary streams (reference sites).

Figure 16. Grouping of fish samples collected in the Snowy River system 2000-2005 and the common fish species represented in these groupings.



These sample groupings are likely to reflect the combined influence of: (i) natural differences/gradients, such as gradients in river water temperature regime between the higher and lower altitude reaches (Vannote *et al.* 1980) on fish distribution; and (ii) the impact of the SMS, including the change in the flow regime, and the associated loss of river habitats (Rose in prep), poorer water quality (Bevitt and Jones 2008) and the loss of fish passage opportunities attributable to flow induced physical barriers (Haeusler and Bevitt 2007).

In the upper catchment, before the implementation of environmental flows, the difference in the fish fauna between the Snowy River sites and the unregulated tributaries appears to reflect the impact of the SMS. Long-finned eel and goldfish were more abundant in the regulated upper reaches of the Snowy River. Craig (2000) suggests that the upstream movement of catadromous species such as Anguillids (ie. eels) have been less affected by the construction and operation of dams than other fish species around the world. Gerhke *et al.* (1995) suggested in the highly regulated rivers in South Eastern Australia, the close relative to the goldfish the exotic carp, *Cyprinus carpio* dominated fish assemblages. Both

Cyprinid species seem to be favoured by lack of variability in river discharge, and can withstand constant low flows and poor water quality.

River blackfish, brown trout and short-finned eel were more abundant in un-regulated tributary streams of the upper Snowy River catchment. These patterns may be a response to the more natural flow regimes such as the three times greater median flows in upper catchment reference tributaries than in the Snowy River (Brooks *et al.* 2007). These observations are consistent with the project hypotheses, particularly as brown trout prefer colder flowing streams (Allen *et al.* 2002). The greater abundance of river blackfish at reference sites may also be a flow related response, as Koster and Crook (2008) suggest that large scale movements of river blackfish coincide with elevated river discharge, the types of events typically missing in the discharge regime of the upper Snowy River.

Most importantly, the upper reaches lacked many of the migratory (diadromous) species that are found in the river below Snowy Falls. There is limited data available on the distribution of diadromous species within the catchment prior to the diversion of flows through the Snowy Mountains Hydro Scheme, but Australian Museum records document the presence of at least congoli and Australian grayling in the upper catchment (although their abundance is unknown). However, the following personal recollection of Mr Kevin Shaefer, a Dalgety resident for 73 years, suggests that larger diadromous species such as Australian bass, Australian grayling and congoli were originally uncommon or absent from the upper catchment, with the angleable fish species present being primarily eels and river blackfish (from Woodford 2005):

"In our leisure time we used to go fishing for blackfish and eels at night time. We used to bag 30 or 40 blackfish at night as well as a dozen eels. In the depression days, in the 1930's, this helped things a bit".

In the lower Snowy River catchment, fish assemblages typically had a greater proportion of diadromous species than the upper catchment. The lower Snowy River sites supported higher abundances of long-finned eel, goldfish, eastern gambusia and congoli than the tributary sites. Additionally, the lower Snowy River supported higher abundances of exotic fish species (ie. eastern gambusia and goldfish) than the tributaries, indicating a response to catchment disturbance.

Assessment of the first environmental release

It is expected that environmental water releases of 21% MANF will be required to achieve a detectable response in fish assemblage variables, and as predicted fish assemblages at sampling sites in the Snowy River have not yet shown a significant response to the first small release of environmental water. The environmental water releases were equivalent of an increase from 1.9 to 3.4% of MANF (as measured at Dalgety). Additionally, the small hydrological response to the new flow regime was only measured in the upper reaches of the Snowy River, and resulted in a doubling of the flowing water habitat in one of the riffles in the upper catchment (Brooks *et al.* 2007).

No significant changes in the fish assemblage variables at test sites in the upper Snowy River were detected between pre and post environmental flow periods. However, unexpectedly, the multi-variate analyses suggest that the fish assemblage of the upper reference sites did change between the pre and post flow periods, with increasing abundance of both mountain galaxias and brown trout. Brooks *et al.* (2007) identified a small reduction in median flow discharge at upland macro-reach reference sites, which is attributable to the drought. It is unclear why the mountain galaxias and brown trout abundance increased during this period, given the reduction in stream flow. However, the changes detected for these two species using multi-variate analyses were not found to be significant when catch-per-unit-effort data for each species was analysed using parametric ANOVA analyses.

In general, no significant changes in the fish assemblage variables at test sites in the lower Snowy River could be attributable to the environmental releases. However a single species, Southern pygmy perch, increased in abundance at test sites, but remained stable (or declined) in abundance at reference sites at the same time, with the flow x location interaction term explaining 37% of the variation in pygmy perch abundance. The increase in the abundance of Southern pygmy perch was coincident with declining flows at both reference and test sites in the lowland macro-reach (Brooks *et al.* 2007). Southern pygmy perch is generally considered a still water or wetland species (Kuiter *et al.* 1996; Allen *et al*. 2002), and the increase in their abundance at test sites may have been a direct result of the 60% decline in median flows in the lower Snowy River. As future environmental flows are delivered to the lowland macro-reaches of the Snowy River, it is expected that flowing water species will be favoured and the abundance of Southern pygmy perch may decline. Further, Southern pygmy perch are not a diadromous species, so in this case the lower zone reference sites are independent of flows in the Snowy River and are appropriate for isolating environmental flow responses from other catchment wide environmental changes.

Fish passage and environmental water releases

Currently, short-finned and long-finned eel were the only two diadromous species capable of regular fish passage past Snowy Falls under reduced flow conditions. Eels are capable of undertaking overland movements and/or climb over instream barriers (Beumer 1996). The remainder of the diadromous species are restricted to undertaking upstream migrations only when ‘drown-out’ flows inundate the major fish barriers, or when bypass channels are created under high flow conditions. Potentially, future environmental water releases to the Snowy River could provide fish passage past (i) Stone Bridge (ii) Corrowong, (iii) Snowy and (iv) Pinch falls, resulting in enhanced fish assemblages in the upper catchment. However, for diadromous fish to access the upper catchment, flow peaks must coincide with periods of peak fish migration and fish passage must be maintained for a period of time to allow a sufficient proportion of the population to pass (Thorncraft and Harris 2000).

The magnitude, frequency, duration and timing of flows required to provide fish passage between the lower and upper catchment (ie. all four major natural barriers) is unknown. However, Haeusler and Bevitt (2007) have estimated the magnitude of discharge required for the passage of Australian Bass at Pinch Falls, a smaller barrier than Snowy Falls. They suggest mean daily discharge rates of 10,370 Mld^{-1} and 13,350 Mld^{-1} are required to provide passage flows for adult and juvenile Australian Bass, respectively. It is clear that during the first three years of environmental water releases that discharge rates of this magnitude were not recorded in the upper Snowy River and this is further supported by the lack of change in the fish assemblages above the Snowy Falls.

The very limited response observed by fish assemblages following the small environmental water allocation is consistent with the results reported for macroinvertebrate assemblages in the Snowy River (Brooks *et al*. 2007). The environmental water released from the Mowamba River between 2003 and 2005 were not sufficient to influence fish assemblage composition in either the upper or lower reaches of the Snowy River catchment.

4.2 IMPACT OF WILDFIRES

Although impacts of the 2003 bushfires could potentially mask some of the comparisons presented, evidence for fire-induced changes to fish assemblages is weak. It is unlikely that the 2003 bushfires compromised our ability to detect changes resulting from increased environmental flows. This response is also consistent with the findings of Russell and Brooks (in prep) who found no lasting fire impacts on the macroinvertebrate assemblages of the Snowy River. The very minor responses in fish assemblage variables observed are probably more a result of the very low level of environmental flow provided during the 2003 – 2005 period, the hydrological consequences of which were restricted to the upper catchment sites.

4.3 PROJECT DESIGN

Overall, temporal variation within fish assemblages sampled during pre-flow release period was low compared to spatial variability within the catchment. Therefore, a repeated measures design (ie. continued annual sampling) is likely to provide a sufficiently powerful means to detect changes resulting from the introduction of 21 % MANF environmental flows. This is supported by studies undertaken in New South Wales by Gehrke and Harris (2000), Gehrke *et al.* (2002) and Growns *et al.* (2003).

The Before -After-Reference- Impact approach (BARI) being applied by the 'Snowy River Environmental Flow Response Monitoring' is an ideal experimental approach for monitoring the response of most of the aquatic features being assessed by the program (see Downes *et al.* 2002). However, given their mobility, the Reference-Impact site approach being used is less appropriate for assessment of fish assemblages. Eleven of the freshwater fish species present within the Snowy River catchment are diadromous, which requires that they either migrate through, and/or spawn within the estuarine reaches of the lower Snowy River (Thorncraft and Harris 2000). As a result, their life history is influenced by the hydrological regime of the Snowy River whether they are resident within a reference tributary or not. Given that few diadromous species are present in the upper catchment, the existing approach should still be appropriate unless the provision of environmental water leads to increased fish passage between lower and upper catchment areas. However, it is far more serious for lowland fish assemblages given the high proportion of species in this zone are obligatory migratory. For the purpose of environmental flow assessment, fish assemblages at reference sites established in the lower catchment are not independent of environmental flows in the Snowy River and do not serve their intended purpose. The implications for the monitoring program are that it should be expected that the fish assemblage in the lower catchment reference sites will also respond to provision of environmental flows in a similar fashion as fish assemblages at test sites. Therefore, it will not be possible to adequately isolate the impacts of the environmental water releases from other catchment processes in the lower reaches.

5. Conclusion

A minor hydrological response was restricted to only the upper macro reaches of the Snowy River (ie. a change of 1.9% to 3.4% of MANF at Dalgety). The small hydrological change attributable to the first increment of the environmental flows has not resulted in a significant response by fish. The lack of a change in the fish assemblages to the first stage of the environmental water releases is not surprising given an expected detectable fish response would not occur until after the release of 21% MANF was recorded.

6. Recommendation

The following recommendation regarding the environmental flow releases needs to be considered by Government:

- Larger volumes of water need to be released in order to see a significant improvement in fish assemblages.

- Events greater than mean daily discharge rates of 10,370 Mld^{-1} and 13,350 Mld^{-1} are likely to be required to provide passage flows for adult and juvenile Australian Bass, respectively at one of the smaller major natural barriers in Upper Snowy River at Pinch Falls. Further consideration of the magnitude, frequency, duration and timing of such events is required for the Snowy River.

The following recommendation regarding the broad- scale fish monitoring program needs to be considered by Government:

- Continued sampling through time should provide a sufficiently powerful means to detect responses by fish assemblages occurring at test sites with the revised flow regime.

- The future sampling design of the fish component of the Snowy Flow Response Monitoring program needs to consider the relevance of the a BARI design particularly where diadromous fish species in the lower reference sites are likely to utilise the lower Snowy River (i.e. the treatment or impact sites). The use of a repeated measures design, or sub setting the data to only include the few species present that are not diadromous, or the development of a predictive fish model (ie. Chessman 2006 and Chessman *et al* 2008) to model lowland reference condition should be further discussed.

- Further assessment of the other three major natural fish barriers would assist in the interpretation of the broad-scale fish monitoring program, and assist in developing new environmental water release rules. If possible, the focus should be applied to the largest barrier to determine the relative magnitude of events required to drown out Snowy Falls. This will then determine the upper limit for the future fish passage releases.

7. References

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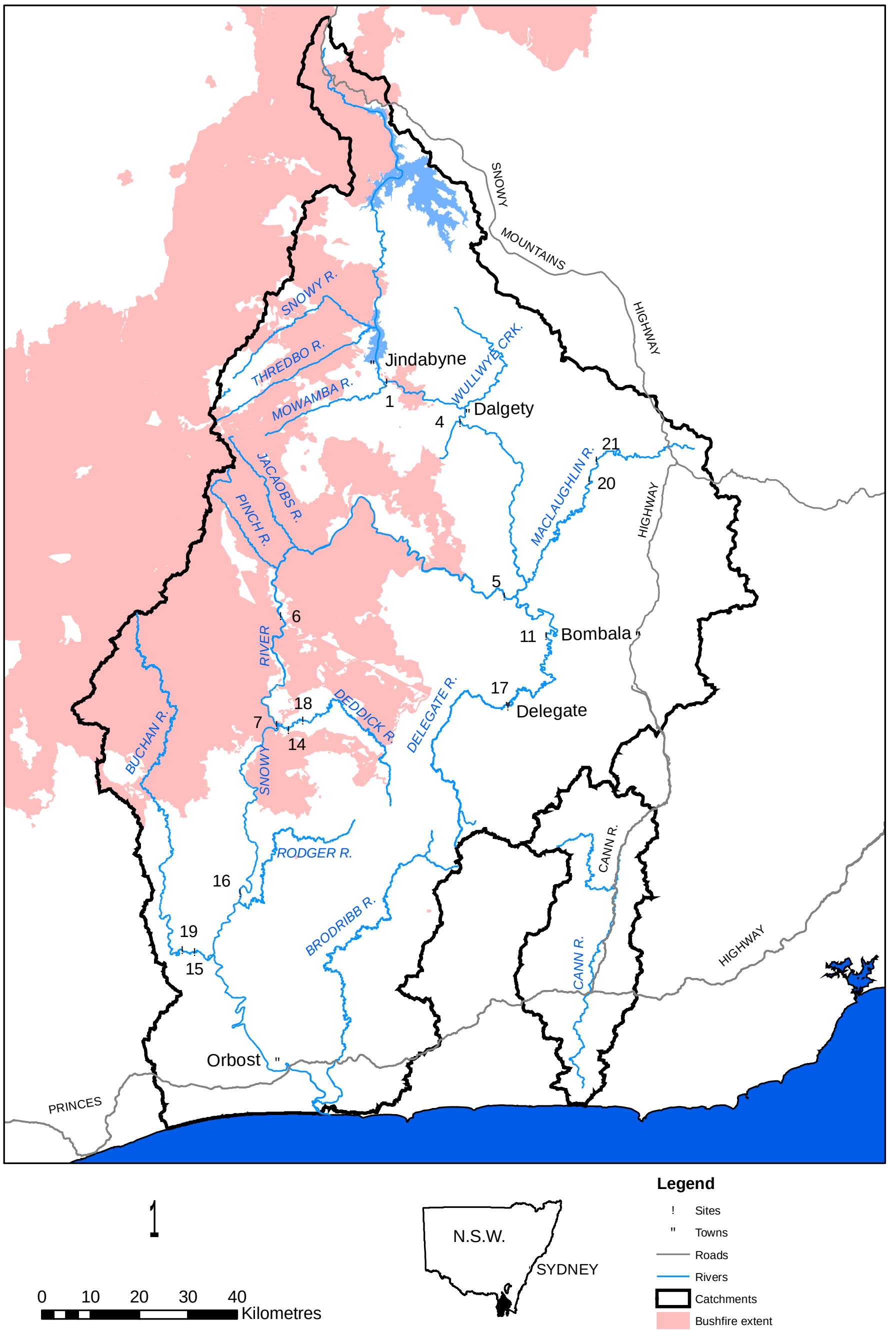
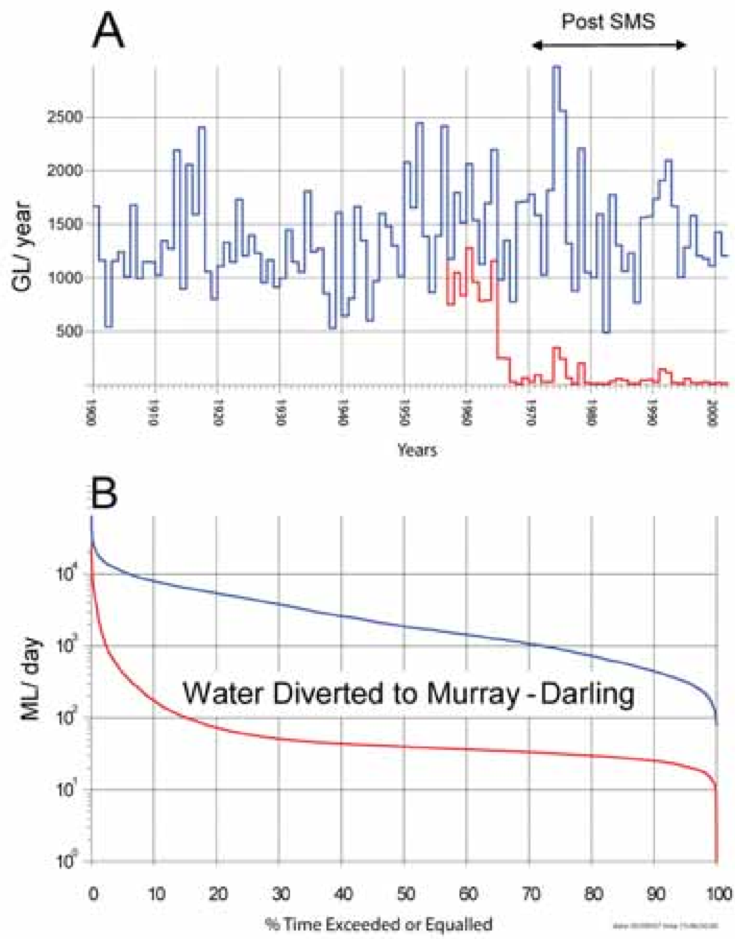
Appendix 1.

Extent of 2002-2003 wild fires in the Snowy River Catchment and fish sampling sites. Prepared by Matt Russell .

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