Biological response to environmental flows below Corin, Bendora, Cotter and Googong Dams

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Front Photograph: Cotter River at site CM1 downstream of Corin Dam, April 2010 (L.Knight)

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Executive summary

1. The Cotter and Queanbeyan Rivers are regulated to supply water to the ACT. Assessment is undertaken in spring and autumn each year at sites below dams on the Cotter and Queanbeyan Rivers, and at reference sites, to meet the requirements of Licence No. WU67 – Licence to take water. The aim of this work is to assess the effects of regulated flow regimes on ecological condition and contribute to adaptive management.

2. In autumn 2010, two below dam sites (CM2 and QM2) were assessed by the AUSRIVAS model as being similar to reference condition whereas site CM1 decreased in biological condition to significantly impaired (Band B) from similar to reference condition (Band A) in autumn 2010. Reference sites on the Goodradigbee and Queanbeyan River were assessed by the AUSRIVAS model as being in better condition than test sites except for the tributary GT3 whereas all three tributaries of the Cotter River were assessed as being impaired.

3. The decrease in biological condition at site CM1 below Corin Dam to pre spring 2009 levels was possibly because a pool flow release of more than 500ML.d^{-1} did not occur a month before sampling. Macroinvertebrate community improvement at QM2 may be a consequence of natural biological improvements of the stream because gradual upgrades have been found at both sites QM1 and QM3 upstream and downstream of QM2 respectively since autumn 2007. However, macroinvertebrate community structure at sites QM2 (Band A) and QM3 (Band B) was still distinctly different with a lower abundance of habitat disturbance and pollution sensitive taxa compared to the site above Googong Dam, indicating that the presence of dam still had a detrimental effect on the macroinvertebrate community downstream of Googong Dam.

4. Deterioration in biological condition at the Cotter River tributary Sites was most likely the result of ongoing drought conditions.

5. Overall, even where an improvement was observed at test sites relative to previous rounds of sampling, the detrimental effect of river regulation on biological macroinvertebrate diversity and richness was still observed compared to unregulated reference sites.

1 Introduction

Water diversions and modified flow regimes often result in deterioration of both the ecological function and water quality of Australian streams (Arthington & Pusey 2003). Many of the aquatic ecosystems in the Australian Capital Territory (ACT) are subject to flow regulation and environmental flow guidelines were introduced in 1999 as part of the Water Resources Act 1998 and redefined in 2006 (ACT Government 1999; 2006). The Environmental Flow Guidelines aim to identify the components of the flow regime that are necessary for maintaining stream health, and set the ecological objectives to be protected by the flow regime (ACT Government 2006). The environmental flow objectives were designed to assess the effectiveness of, and refine the environmental flow regime. An assessment program also regularly assesses the effectiveness of the flow regime for meeting the ecological objectives and informs recommendations to refine future environmental flow releases.

Ongoing drought in the ACT has lead to modifications of the environmental flow releases. In 2004 the ACT Government introduced 'drought flows' below dams on the Cotter River based on minimum flows of 20 MLd^{-1} with a flushing flow approximately every two months (Peat and Norris 2007). The Environmental Flow Guidelines (2006) also recognised that drought may necessitate a reduction in the volume of environmental flow releases in water supply catchments to ensure ongoing water security. For example, when water restrictions of Stage 1 or more are applied to the ACT, the two monthly flushing flows need not be released below either Cotter or Googong Dams. However, further changes to environmental flow releases were made in December 2006, when flows were reduced to an average of only 5 MLd^{-1} below Cotter Dam to conserve more water. During drought flows, flow variability is maintained where the volume of environmental flow releases is reduced (e.g. Peat and Norris 2007; Norris *et al*. 2007; White and Norris 2008a) in an attempt to maintain river condition. Assessment of the ecological objectives of environmental flow regimes in the ACT has been ongoing and includes assessment of macroinvertebrates, periphyton, water quality and riffle sediment as part of the general license requirements.

Now, during construction and subsequent filling of the Enlarged Cotter Dam there will be minimal capacity to release water from the reservoir to the lower Cotter River. The Murrumbidgee to Cotter pumping augmentation (M2C) project has been implemented to provide an environmental flow transfer capability for the Cotter River reach below Cotter Dam by pumping water from Murrumbidgee River. It is proposed that flow from the M2C will be 20-40 MLd^{-1} but the volume may depend on the flow level in the Murrumbidgee River.

Sampling is conducted during autumn and spring of each year to evaluate the condition of sites below dams on the Cotter and Queanbeyan Rivers in comparison to the condition of reference sites on the unregulated Goodradigbee River, Cotter and Goodradigbee River tributaries as well as upstream of Googong Dam. The program includes assessment of the macroinvertebrate community, water quality, periphyton and an annual riffle sediment survey (autumn). The results of the assessment program provide ecological information that assist in making informed management decisions regarding the regulated flows of the Cotter and Queanbeyan Rivers, ensuring that these valuable resources are appropriately protected.

The aim of this study is to address the needs of ACTEW's License to Abstract Water (WU67) in assessing the effects of dam operation, water extraction and the effectiveness of

environmental flows and to provide information for the adaptive management of the water supply catchments. This report focuses on the macroinvertebrate, periphyton and water quality components of the study.

2 Materials and methods

2.1 Study area

The study area includes the Cotter and Goodradigbee Rivers, which are situated along the western border of the ACT and east of the border in NSW, respectively. The Cotter River is a fifth order stream (below Cotter Dam) with a catchment area of approximately 480 km^2. The Cotter River is a major source of water for Canberra, with the principal management outcome to ensure a secure water supply (ACT Government 2006). Conservation of ecological values of the river is an important consideration in the ongoing management of the Cotter River. The river is regulated by three dams, the Cotter Dam, Bendora Dam and Corin Dam. The operational requirements of each dam on the Cotter River differs according to a number of variables including reservoir levels, demand, and water quality, Corin Dam releases water to the river channel to maintain water levels in Bendora Reservoir, which is often the primary reservoir relied on for supply. A gravity main supplies water from Bendora Dam to Stromlo Water Treatment Plant, where water is treated prior to distribution to the cities of Canberra and Queanbeyan. Overall, minimal releases occur to the river except for designated environmental flow purposes. The Cotter River catchment has restricted public access, and is largely free of pollutants and human disturbance aside from regulation, which provides the opportunity to study the effects of flow releases from the dams without many of the confounding factors often present in environmental investigations (Chester and Norris 2006; Nichols *et al.* 2006).

The study area also includes the Queanbeyan River, which is located to the east of the ACT border in NSW. The Queanbeyan River is a fifth order stream (at all sampling sites) regulated by Googong Dam approximately 90 km from its source. Similar to the Cotter River, the primary goal for the Queanbeyan River above Googong Dam is to secure the water supply for the ACT and Queanbeyan.

The Goodradigbee River is located to the west of the ACT border within NSW. The Goodradigbee River is a fifth order stream (at all sampling sites), which remains largely unregulated until it reaches Burrinjuck Dam (near Yass). This fifth stream order river constitutes an appropriate reference site to assess of a potential effect of environmental flow regimes on stream ecological health in the ACT.

2.2 Site selection

Fifteen sites were sampled for macroinvertebrates and physicochemical water quality variables (Fig. 1; Table 1). Three sites were on the Cotter River (CM1, CM2, CM3), one below each dam, each with a nearby tributary site (CT1, CT2, CT3). These sites were then replicated on the unregulated Goodradigbee River (GM1, GM2, GM3) and three of its tributaries (GT1, GT2, GT3). Three sites were also sampled on the Queanbeyan River, one upstream of Googong Dam (QM1) and two downstream of the dam (QM2, QM3). The inclusion of the unregulated main channel and tributary sites enables a better understanding of the effects of different environmental flows and changes resulting from natural events relative to the condition of naturally flowing rivers (Peat and Norris 2007).

Table 1: Cotter, Goodradigbee and Queanbeyan River sampling sites for the below dams licence program, autumn 2010.

Site Code	River	Location	Altitude (m)	Distance from source (km)	Stream order
CM1	Cotter	500 m downstream of Corin Dam	900	31	4
CM2	Cotter	500 m downstream of Bendora Dam	700	51	4
CM3	Cotter	100 m upstream Paddy's River confluence	500	75	5
CT1	Kangaroo Ck	50 m downstream Corin Road crossing	900	7.3	3
CT2	Burkes Creek	50 m upstream of confluence with Cotter River	680	4.5	3
CT3	Paddy's	500 m upstream of confluence with Cotter River	500	48	4
GM1	Goodradigbee	20 m upstream of confluence with Cooleman Ck	680	38	5
GM2	Goodradigbee	20 m upstream of confluence with Bull Flat Ck	650	42	5
GM3	Goodradigbee	100 m upstream of Brindabella Bridge	620	48	5
GT1	Cooleman Ck	50 m upstream of Long Plain Road crossing	680	17.9	4
GT2	Bull Flat Ck	Immediately upstream of Crace Lane crossing	650	15.6	4
GT3	Bramina Ck	30 m upstream of Brindabella Road crossing	630	18	5
QM1	Queanbeyan River	12 km upstream of Googong Dam near 'Hayshed Pool'	720	72	5
QM2	Queanbeyan River	1 km downstream of Googong Dam	590	91.6	5
QM3	Queanbeyan River	2 km downstream of Googong Dam at Wickerslack Lane	600	96	5

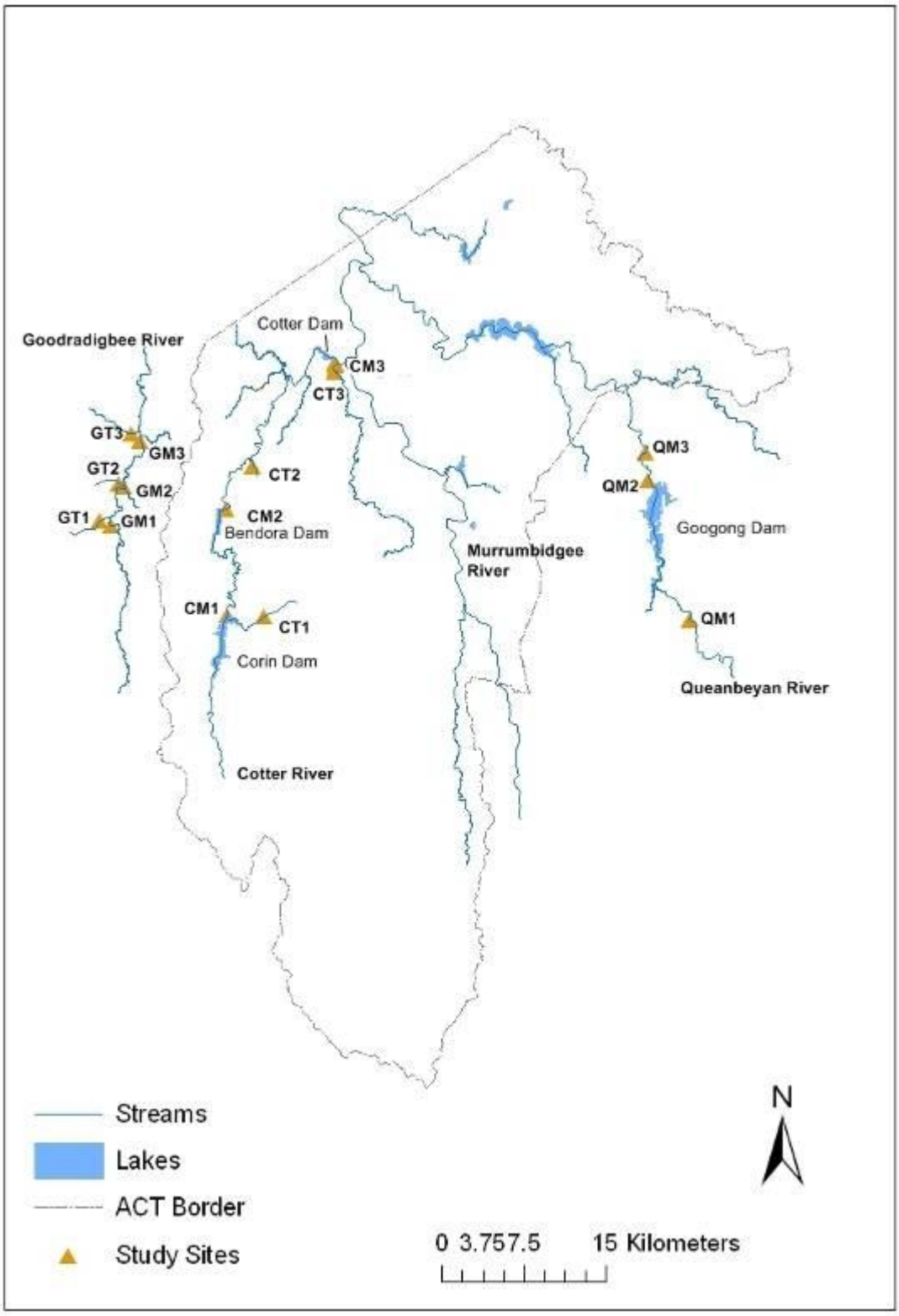

Figure 1: The location of the Cotter, Goodradigbee and Queanbeyan River's sampling sites and tributaries, autumn 2010.

2.3 Sampling period

As per the licence conditions, sampling was undertaken during autumn between the 8th April and the 29th April 2010 (Table 2).

Table 2: Sampling dates and times for each site sampled, autumn 2010.

SITE	SAMPLING DATE	SAMPLING TIME
CM1	22/4/2010	12:30pm
CM2	29/4/2010	12:30pm
CM3	10/4/2010	11:30am
CT1	22/4/2010	10:30am
CT2	29/4/2010	11:00am
CT3	10/4/2010	11:30am
GM1	8/4/2010	2:00pm
GM2	8/4/2010	11:40am
GM3	8/4/2010	9:45am
GT1	8/4/2010	3:00pm
GT2	8/4/2010	12:50pm
GT3	8/4/2010	10:50am
QM1	28/4/2010	11:35am
QM2	28/4/2010	10:05am
QM3	28/4/2010	1:15pm

2.4 Hydrometric data

Mean daily flow data was obtained for Corin, Bendora, Cotter and Googong Dams on the Cotter and Queanbeyan Rivers from ActewAGL. Mean daily flow data was also obtained for the Goodradigbee River at site GM2 from the Department of Water and Energy in NSW. Daily rainfall data for Canberra was also obtained from the Bureau of Meteorology (http://www.bom.gov.au/climate/dwo/). Both rainfall and flow data covered the sampling period, ranging from the 10th March and the 1st May 2010.

2.5 Sampling sites

Site characteristics including latitude, longitude, altitude, stream order, catchment area, and distance from source were obtained from 1:100 000 topographic maps. Latitude and longitude were confirmed in the field using a Global Positioning System.

2.6 Physical and chemical water quality assessment and guidelines

Water temperature (^{o}C), dissolved oxygen (as %DO & mg L^{-1}), pH, conductivity (EC, µS cm^{-1}) and turbidity (NTU) were measured at all sites using a calibrated Hydrolab DS5 Multiprobe. Total alkalinity was calculated by field titration to an end point of pH 4.5 (APHA 1992). Water velocity was measured with a calibrated Hydrological Services CMC20 flow meter.

Water quality trigger values from the ANZECC and ARMCANZ (2000) guidelines were used for comparison of water quality conditions compared to a baseline reference. Specifically, the guidelines used were those for an upland river system in south-east Australia, which includes the ACT (Table 3). While comparisons with the guidelines are not required as part of the environmental flow guidelines, and should be used only as a guide, the guidelines are a useful tool for the protection of ecosystems, which is a primary objective of environmental flows.

Table 3: Water quality trigger values for aquatics ecosystems in upland rivers in south-east Australia (from ANZECC & ARMCANZ 2000). N/A = *trigger value not available*.

Parameter	Units	Trigger value
Alkalinity	mg L^{-1}	N/A
Temperature	ºC	N/A
Conductivity	µS cm^{-1}	30 - 350
pH	N/A	6.5-8
Dissolved Oxygen	mg L^{-1}	N/A
Dissolved Oxygen	% saturation	90 - 110
Turbidity	NTU	2.0 - 25
Ammonia	mg L^{-1}	N/A* detection limit of assay = 0.0005
Oxidised Nitrogen	mg L^{-1}	<0.015
Total Phosphorus	mg L^{-1}	<0.02
Total Nitrogen	mg L^{-1}	<0.25

2.7 Macroinvertebrates

Biological measurements are particularly useful for assessing river health. Studying river ecology shows the temporal changes occurring in watercourses because biota populations change over time, depending on the aquatic conditions. Biological measurements can detect the effects of events that may pass unnoticed by periodic physical and chemical sampling, because these instantaneous measurements only give an indication of the river condition at the time of sampling.

Benthic macroinvertebrates were sampled from the riffle habitat using a framed net 350 mm across the bottom with a mesh size of 250 µm. Collection of macroinvertebrates, recording and measurement of water quality and physical habitat variables followed National River

Health Program protocols presented in the ACT AUSRIVAS sampling and processing manual (Nichols *et al.* 2000, http://AUSRIVAS.canberra.edu.au/AUSRIVAS).

In the laboratory, preserved samples were placed in a sub-sampling box comprising of 100 cells (Marchant 1989) and agitated until evenly distributed. Contents of each cell were removed until approximately 200 animals from each sample were identified (Parsons and Norris 1996). Macroinvertebrates were identified to the family taxonomic level using keys listed by Hawking (2000), except Chironomidae, which were identified to sub-family, and worms (Oligochaeta) and mites (Acarina), which were identified to class. After the ~200 macroinvertebrates were sub-sampled, the remaining unsorted sample was placed into a large white tray with water to evenly distribute the sample. This sample was then visually scanned with a large magnifying lamp for 15 minutes and any taxa, which were not found in the ~200 animal sub-sample, were collected for identification (Nichols *et al*. 2000). By conducting a visual scan, a more complete taxa list can be obtained, incorporating large and rare taxa that may not have been collected in the ~200 organism sub-sample. This method of scan sampling was not used in the construction of the AUSRIVAS model and therefore the macroinvertebrates collected in the scan cannot be used when making site assessments using the Australian River Assessment System (AUSRIVAS) predictive models – see section 2.7.3 (Coysh *et al.* 2000; Simpson and Norris 2000). The results from the visual scan are thus recorded separately from the ~200 organism sub-sample records and should be regarded as a separate data set.

2.7.1 Macroinvertebrate quality control/quality assurance procedures

Quality control/quality assurance procedures are designed to establish an acceptable taxonomic standard of macroinvertebrate sorting and identifications. The quality control (QC) component controls error and variation in the macroinvertebrate data, and quality assurance (QA) provides assurance that the accuracy of results is within controlled and acceptable limits. The following internal QA/QC procedures were implemented for macroinvertebrate sample processing.

- All samples were separated into Orders and placed in separate vials to eliminate any high level discrepancies. This was also required for future curatorial preservation and storage.

- When an identification problem was encountered a decision tree for identifications (Hawking and O'Conner 1997) was followed. The decision tree has been reproduced in the ACT AUSRIVAS sampling and processing manual (Nichols *et al*. 2000). Very small, damaged, immature animals or pupae that were unable to be identified with confidence were noted as such and were not included in the taxa list for that sample. The counts for unidentified animals were not included in the 200-organism sub-sample.

- Damaged animals were identified if possible, recorded and placed in the appropriate vials. If a specimen could not be identified it was noted as such (e.g. Ephemeroptera damaged) and placed in the appropriate vial.

- A quality control staff member checked the first five samples identified by each person.

- A miss-identification error of < 5 % of the total number of animals was deemed acceptable at family level. If the error was ≥ 5 %, the miss-identifications were corrected under the guidance of quality control staff. All miss-identifications were shown to the person and suitable instruction given to rectify the miss-identification. Other samples containing the same miss-identified taxa were checked by the original identifier for miss-identification errors and corrected if necessary.

- Following the initial checking of five samples, a random selection of two samples in the following 10, were checked.

- Persons checking samples were those who have passed the AUSRIVAS QAQC procedure outlined in Nichols *et al.* 2000 and accredited in macroinvertebrate identification.

2.7.2 Macroinvertebrate community structure

Benthic invertebrate richness and relative numbers can provide valuable information about a river's condition. Taxa such as Oligochaeta (worms), Gastropoda (freshwater snails), Diptera (true flies), and particularly Chironomidae (midge larvae) are either tolerant or thrive in nutrient rich environments. These organisms are found in all river systems, but large numbers of these taxa relative to more sensitive taxa can indicate a disturbed or unhealthy river environment. Alternatively, most Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddis flies), and some Coleoptera (beetles) are sensitive to reduced water quality and habitat alterations. Thus, high relative numbers of these organisms, in an aquatic ecosystem, indicates a healthy river system. The AUStralian RIVer Assessment System (AUSRIVAS) is also used to further analyse the macroinvertebrate community structure and provide an assessment of stream condition (Simpson and Norris, 2000).

2.7.3 Macroinvertebrate Predictive models - AUSRIVAS (AUStralian RIVer Assessment System)

AUSRIVAS predicts the macroinvertebrate fauna expected to occur at a site with specific environmental characteristics, in the absence of environmental stress. The fauna observed (O) at a site can then be compared to fauna expected (E), with the deviation between the two providing an indication of biological condition (Coysh *et al*. 2000, http://AUSRIVAS.canberra.edu.au). A site displaying no biological impairment should have an O/E ratio close to one. The O/E ratio will decrease as the macroinvertebrate assemblage and richness is adversely affected. In addition to calculating the expected number of taxa at a site, AUSRIVAS also calculates the expected SIGNAL (Stream Invertebrate Grade Number - Average Level) score for a site, as shown in Table 6 (Chessman 1995).

2.7.4 AUSRIVAS Autumn Riffle Model

The AUSRIVAS predictive model used to assess the biological condition of sites was the ACT Autumn Riffle model. The AUSRIVAS software and Users Manual (Coysh *et al.* 2000) is available online at: *http://AUSRIVAS.canberra.edu.au.* Also provided in the manual is a comprehensive explanation of how the AUSRIVAS predictive models are constructed, the statistical workings of the models, details on interpretation of the outputs, and how to gain a password to run AUSRIVAS. The ACT autumn riffle model uses a set of 12 habitat variables to predict the macroinvertebrate fauna expected at each site (Table 4).

Table 4: Habitat variables used by the ACT autumn riffle AUSRIVAS model to predict the macroinvertebrate fauna expected at a site.

Variable	Description
ALTITUDE	Height above sea level (m)
CATCHAREA	Catchment area upstream of site (km^2)
DFS	Distance from source (km)
LONGITUDE	Longitude (Degrees/Minutes eg. 14857)
PEBBLE	Percent cover in edge of pebble (16-64 mm)
STORDER	Stream order calculated from 1:100,000 map
GFS	Percent cover of riparian zone by grasses, ferns and sedges.
ALKALINITY	Total carbonates. ($mg\ L^{-1}$)
BOULDER	Percent boulder [>256mm] in habitat. (%)
COBBLE	Percent cobble [64-256mm] in habitat. (%)
RIPWIDTH	Width of the riparian zone; mean from both banks. (m)
SHRUBVINE	Percent cover of riparian zone by shrubs and vines. (%)

2.7.5 Biological condition bands for the AUSRIVAS Autumn Riffle Model

To simplify interpretation and aid management decisions, AUSRIVAS allocates O/E taxa scores to category bands that represent a range in biological conditions. AUSRIVAS uses five bands, designated X, A, B, C, and D (Table 5). The derivation of bandwidths is based on the distribution of O/E scores of the reference sites used to create the AUSRIVAS models (Coysh *et al.* 2000*,* *http://AUSRIVAS.canberra.edu.au*). When using the Autumn Riffle model, test site scores that fall between 0.88-1.12 (Band A) are considered similar to reference condition). A significantly impaired site will have an O/E score between 0.64 and 0.87 (Band B); a severely impaired site (Band C) will have an O/E score between 0.40 - 0.63; and the extremely impaired sites will have an O/E score of 0 - 0.39 (Band D) . Sites that have O/E scores ≥1.13 (Band X) are considered to be more biologically diverse than reference. Allocation to Band X should result in further assessment to determine whether the site is richer than reference because of naturally high diversity or an impact such as mild nutrient enrichment.

Table 5: Band label, upper limit, name and description, autumn variables.

Band	Band Description	O/E Taxa Scores	O/E Taxa Interpretations
X	MORE BIOLOGICALLY DIVERSE THAN REFERENCE	**Band X ≥1.13**	More taxa found than expected. Potential biodiversity hot-spot. Possible mild organic enrichment.
A	SIMILAR TO REFERENCE	**Band A 0.88-1.12**	Most/all of the expected families found. Water quality and/or habitat condition roughly equivalent to reference sites. Impact on water quality and habitat condition does not result in a loss of macroinvertebrate diversity.
B	SIGNIFICANTLY IMPAIRED	**Band B 0.64-0.87**	Fewer families than expected. Potential impact either on water quality or habitat quality or both resulting in loss of taxa.
C	SEVERELY IMPAIRED	**Band C 0.40-0.63**	Many fewer families than expected. Loss of macroinvertebrate biodiversity due to substantial impacts on water and/or habitat quality.
D	EXTREMELY IMPAIRED	**Band D 0-0.39**	Few of the expected families remain. Extremely poor water and/or habitat quality. Highly degraded.

2.7.5 SIGNAL grades

To aid the interpretation of results, habitat disturbance and pollution sensitivity (SIGNAL) grades for macroinvertebrate taxa commonly predicted with ≥50% chance of occurrence are provided (Table 6). Grades range from 1 to 10, with sensitive taxa receiving high scores and tolerant taxa low scores. The sensitivity grades are based on taxa tolerance to common pollution types (Chessman 1995). Several changes have been made to the original SIGNAL

grade numbers to better reflect the pollution sensitivities of different families. These new grade numbers are referred to as the SIGNAL two, grade numbers, and have been incorporated into the AUSRIVAS platform. A banding scheme for O/E SIGNAL has not been developed.

Table 6: Habitat disturbance and pollution sensitivity (SIGNAL) grades for macroinvertebrate taxa commonly predicted with a ≥50% chance of occurring.

Taxa	Grade	Taxa	Grade
Acarina	6	Helicophidae	10
Aeshnidae	4	Helicopsychidae	8
Amphipoda	3	Hydrobiidae	4
Ancylidae	4	Hydrobiosidae	8
Aphroteniinae	8	Hydrophilidae	2
Athericidae	8	Hydropsychidae	6
Atriplectididae	7	Hydroptilidae	4
Atyidae	3	Leptoceridae	6
Austroperlidae	10	Leptophlebiidae	8
Baetidae	5	Lymnaeidae	1
Caenidae	4	Notonectidae	1
Calamoceratidae	7	Notonemouridae	6
Calocidae	9	Odontoceridae	7
Ceratopogonidae	4	Oligochaeta	2
Chironominae	3	Orthocladiinae	4
Coenagrionidae	2	Philopotamidae	8
Coloburiscidae	8	Physidae	1
Conoesucidae	7	Planorbidae	2
Corbiculidae	4	Podonominae	6
Corduliidae	5	Polycentropodidae	7
Corixidae	2	Psephenidae	6
Corydalidae	7	Pyralidae	3
Dixidae	7	Scirtidae	6
Dytiscidae	2	Simuliidae	5
Ecnomidae	4	Sphaeriidae	5
Elmidae	7	Stratiomyidae	2
Empididae	5	Synlestidae	7
Glossosomatidae	9	Tanypodinae	4
Gomphidae	5	Tipulidae	5
Gripopterygidae	8	Turbellaria	2

2.8 Data entry and storage

The water characteristics, habitat data from field data sheets, and macroinvertebrate data with national taxa codes were entered into an Open Office database. The layout of the database matches the field data sheets to minimise transcription errors. All data were checked for transcription errors using standard two person checking procedures. A backup of files was carried out daily.

2.9 Ash-free dry mass and chlorophyll-a

At sites below dams, CM1, CM2, CM3 and QM2, twelve individual rocks, selected at random, were scrubbed for periphyton. These samples were obtained using a syringe sampler based on two 60 ml syringes and the scrubbing surface of nylon bristles that brushed an area of 637 mm^2, similar to that described by Loeb (1981). The twelve samples from each site were separated into two groups of six. One set of six was used to obtain a measure of Ash Free Dry Mass (AFDM), being dried in an oven at 45 ^oC for 2 hours, weighed, then ashed in a furnace at 500 ^oC for one hour and reweighed. The other samples were used to obtain a measure of chlorophyll-a using 90% ethanol, and measured in a spectrophotometer (Franson 1985).

2.10 Data analysis

Differences between sites in periphyton AFDM and chlorophyll-a were tested using a single factor Analysis of Variance (ANOVA, SAS 9.1), followed by a Tukey studentized range test to reveal the level of significance in differences. A log10(x+1) transformation was applied to both the AFDM and chlorophyll-a data, before undertaking an ANOVA, to ensure data met the assumption of normality.

The relationships among sites based on their macroinvertebrate composition (based on abundance data) were examined using multidimensional scaling (MDS) ordination. Results were accepted in two dimensions if a stress level <0.2 was achieved, indicating that the multidimensional solutions were not random. Abundance data was fourth root transformed to reduce the influence of highly abundant taxa, which may skew the data. A one way analysis of similarity (ANOSIM) (Clarke and Green 1998) was conducted on the matrix to test similarity between test and reference groups. This performs a global test and generates an R statistic ranging between 0 and 1. Based on the recommendations of Clarke and Gorley (2001) an R statistic <0.3 implies little or no difference among the groups; R >0.3 but <0.75 indicates that the groups were different but overlapping in multivariate space and; R >0.75 indicates a complete separation of groups. If there was a difference between groups, a Similarity percentages analysis (SIMilarity PERcentages: Clarke and Warwick 2001) was used to determine the percentage contribution each family made to the similarity within groups. SIMPER also reports a consistency ratio, which is an indication of how consistent the contribution is to all inter-sample comparisons within or among groups and therefore how reliable the species is as a contributing species. Generally a consistency ratio >1.4 is viewed as a reliable means of assigning good discriminators between groups (Clarke and Warwick 2001). All multivariate analyses were conducted using PRIMER 6.

3 Results

3.1 Hydrometric data

The flow in the Goodradigbee River, measured at site GM2 was greater than at below dams sites at the time of sampling, which represents an unregulated flow regime and the basis for comparison against regulated sites (Fig. 3). Peaks in flow in the Goodradigbee River generally matched rainfall events.

The function of each dam on the Cotter River differs, and the hydrographs downstream of each illustrate the release regimes from each reservoir. Corin Dam releases water (from 10 to 150ML.d^{-1}) to the river channel to maintain water levels in Bendora Reservoir before distribution via gravity to Mt Stromlo WTP and then into Canberra's reticulation system. Riffle maintenance flows were released below Bendora Dam between the 18th and 19th March and the 10th and 11th April (Fig. 3). Below Corin Dam a riffle maintenance flow was released between the 23rd and 25th March.

No riffle maintenance flows of 150 ML d^{-1} were released below Googong and Cotter Dams. Flow releases were low below Googong Dam, with a peak in flow of only 28 MLd^{-1} during the study period. Downstream of Cotter Dam flows between 50 - 206 ML d^{-1} were released from the dam to prevent water in the Dam spilling over into the Enlarged Cotter Dam construction site prior to sampling (Fig. 3). Following this, flow in the Cotter River has remained between 9 - 39 ML d^{-1} with the introduction of water transfers from the Murrumbidgee River into the Cotter River downstream of the Cotter Dam.

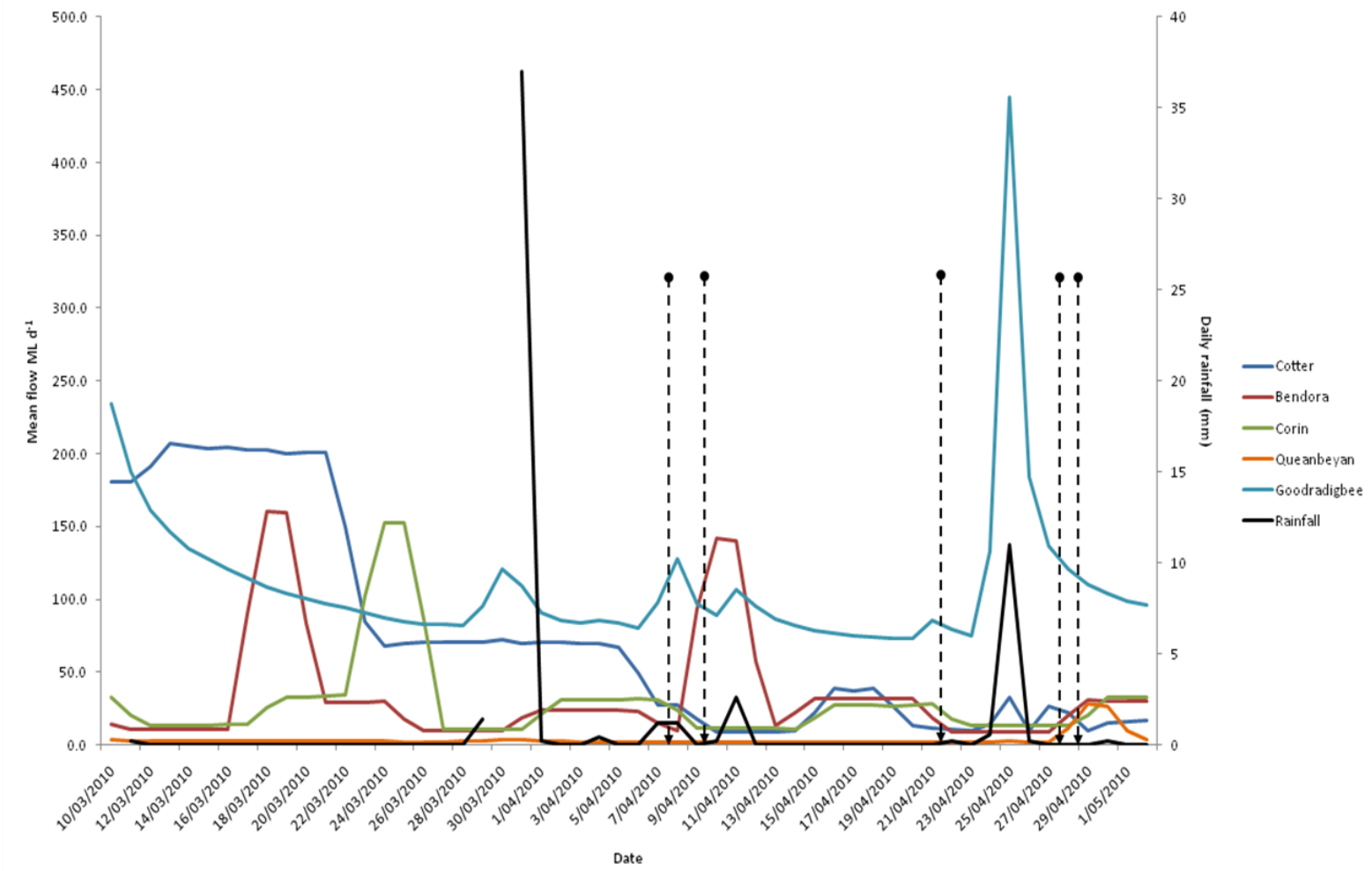

Figure 2: Hydrograph of the Cotter, Goodradigbee and Queanbeyan Rivers: below Corin (CM1), Bendora (CM2), Cotter (CM3) and Googong (QM2) Dams, and Goodradigbee River (GM2); and daily rainfall data for Canberra between 10/3/2010 to 1/5/2010. (Note: Dotted arrows indicate sampling dates and a gap in the rainfall data is a result of missing data). Data source: ACTEWAGL and NSW Department of Water and Energy; Bureau of Meteorology

3.2 Physical and chemical water quality characteristics

Electrical conductivity (µS cm^{-1})

Conductivity at sites CM2 was slightly below the recommended ANZECC & ARMCANZ 2000 guidelines for conductivity (30 - 350 µS cm^{-1}) (Table 7). All other sites were within the recommended range.

pH

All sites had pH levels within the recommended guideline levels (6.5 – 8.0) at the time of sampling, except for reference sites GM1 and GM2 which were slightly above the upper guideline level of 8 (Table 7).

Dissolved oxygen (% saturation)

Measures of percent dissolved oxygen were within the recommended trigger value level at all sites (Table 7).

Turbidity (NTU)

All sites were within the trigger value range of 2 and 25 NTU (ANZECC & ARMCANZ 2000) or had readings of less than 2 NTU at the time of sampling (Table 7).

Ammonia (NH_3)

Ammonia concentrations were below the detection limit (<0.0005 mg L^{-1}) at all sites excluding below dam test site CM1 as well as reference sites CT3, and GM3 (Table 8).

Oxidised Nitrogen (NO_X)

Reference site QM2 and test site CM3 on the Cotter River were above the ANZECC trigger value for NO_x while all other sites were below the trigger value (Table 8).

Total Phosphorus (TP)

Total phosphorus was equal to or below the ANZECC trigger value for all sites (Table 8).

Total Nitrogen (TN)

Total nitrogen was above the ANZECC trigger value at below dam sites CM3, CT3, QM2 and QM3 (Table 8).

Table 7: Water quality characteristics of sites downstream of the dams along the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1), the Goodradigbee reference sites (GM1, GM2, GM3), tributaries of the Goodradigbee River (GT1, GT2, GT3) and main channel sites on the Queanbeyan River (QM1, QM2 and QM3), autumn 2010. *Shading indicates those sites with values not within the trigger value range for aquatic ecosystems in upland rivers in south eastern Australia (ANZECC/ARMCANZ 2000).* N/A = trigger value not available**.**

Site	Alkalinity (mg L^{-1})	Water Temp (^{0}C)	Conductivity (µS cm^{-1})	pH	Dissolved Oxygen (mg L^{-1})	Dissolved Oxygen (%sat)	Turbidity (NTU)
				Trigger value			
	N/A	N/A	30 - 350	6.5 - 8	N/A	90 - 110	2.0 - 25
CM1	10	16.20	30.2	7.02	8.97	97.1	1.0
CM2	22	15.74	28.9	7.18	9.11	100.5	0.0
CM3	22	18.86	58.4	7.06	7.85	91.1	9.2
CT1	30	9.61	54.4	7.18	10.12	95.2	1.0
CT2	20	12.06	34.0	6.94	9.82	98.7	1.6
CT3	24	17.01	137.5	7.87	7.85	105.3	7.7
GM1	71	15.72	96.4	8.19	9.98	101.9	0.0
GM2	60	15.48	93.3	8.01	9.90	100.5	0.0
GM3	78	15.39	105.7	7.90	9.78	99.2	0.2
GT1	38	15.66	63.1	7.83	9.56	97.6	3.6
GT2	52	15.38	66.9	7.78	9.59	97.1	7.1
GT3	42	15.35	58.8	7.76	9.85	99.8	0.8
QM1	41	12.03	85.7	7.14	9.58	95.1	0.62
QM2	62	16.28	135.6	7.69	9.13	99.5	1.0
QM3	78	14.08	221.0	7.63	8.45	87.7	1.0

Table 8: Total Phosphorus, Total Nitrogen, NH_3 and NO_X concentrations, autumn 2010. *Shading indicates those sites with values above the trigger value for aquatic ecosystems in upland rivers in south eastern Australia (ANZECC/ARMCANZ 2000) or above the detection limit of the assay for Ammonia. ** Indicates the detection limit for ammonia.* Trigger values for south eastern Australian upland aquatic ecosystems (ANZECC/ARMCANZ 2000).*

Site	NH_3 (mg L^{-1})	NOx (mg L^{-1})	TP (mg L^{-1})	TN (mg L^{-1})
	Detection value	Trigger value		
	0.0005**	0.015*	0.02*	0.25*
CM1	<0.0005	<0.01	<0.01	0.17
CM2	<0.0005	<0.01	<0.01	0.23
CM3	0.02	0.05	0.01	0.3
CT1	0.01	<0.01	0.01	0.03
CT2	<0.0005	<0.01	<0.01	0.02
CT3	<0.0005	<0.01	0.02	0.43
GM1	<0.0005	<0.01	<0.01	0.03
GM2	<0.0005	<0.01	<0.01	0.06
GM3	0.01	<0.01	<0.01	<0.01
GT1	<0.0005	<0.01	0.01	0.12
GT2	<0.0005	<0.01	0.01	0.18
GT3	<0.0005	<0.01	0.01	0.21
QM1	<0.0005	<0.01	<0.01	0.24
QM2	<0.0005	0.02	<0.01	0.42
QM3	<0.0005	<0.01	<0.01	0.38

3.3 Periphyton and algae: Ash-Free Dry Mass (AFDM), Chlorophyll-a and visual observations

The mean AFDM of periphyton was highest at site CM2 (134889.20 mg m^{-2}) (Fig. 3). However, there was considerable variability around the means, thus no significant differences were detectable between any of the four sites (DF=3,20; F=1.44; p=0.26) (Fig. 3). The chlorophyll-a content of periphyton was highest at site CM3 and this was significantly higher than the chlorophyll-a content at sites CM1 and CM2 (DF=3,20; F=4.26; p=0.02) (Fig. 5).

Visual observations of the percent cover of periphyton in both the riffle and reach habitats were greatest at site CM3, below Cotter Dam (Table 9). All other sites below dams and reference sites on the Goodradigbee River had less than 10% periphyton cover of both the riffle and reach (Table 9). Filamentous algae cover was less than 10% at all test sites on the Cotter and Queanbeyan Rivers and reference sites on the Goodradigbee River (Table 9)

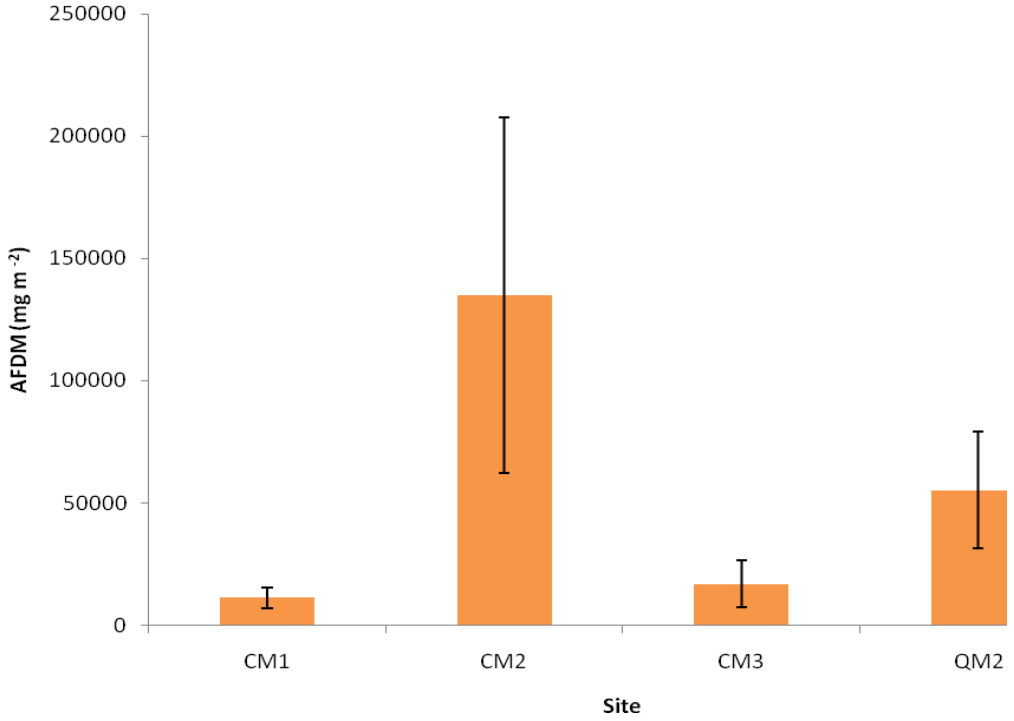

Figure 3: Mean AFDM (mg m^{-2}) at sites CM1 (Corin), CM2 (Bendora) CM3 (Cotter) and QM2 (Googong) below dams in the ACT, autumn 2010. (Note: error bars represent the standard error of the mean)

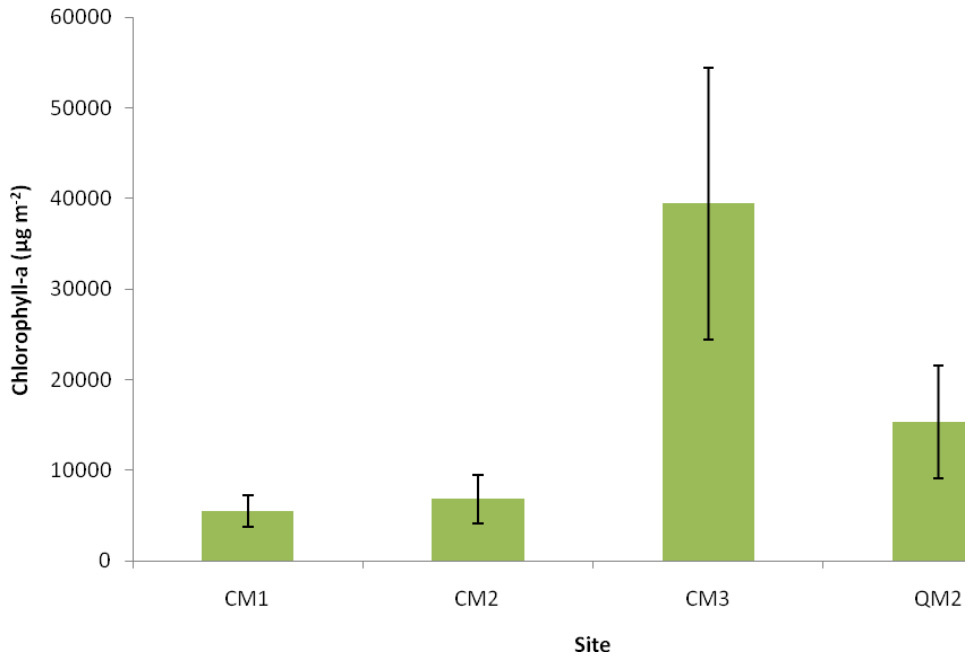

Figure 4: Mean chlorophyll-a (µg m^{-2}) at sites CM1 (Corin), CM2 (Bendora) CM3 (Cotter) and QM2 (Googong) below dams in the ACT, autumn 2010. (Note: error bars represent the standard error of the mean).

Table 9: Percent cover categories of periphyton and filamentous algae in the riffle and reach in the Cotter (CM1, CM2, CM3), Queanbeyan (QM2) and Goodradigbee (GM1, GM2, GM3) River sites, autumn 2010.

	% Cover of Riffle		% Cover of Reach	
SITE	**Periphyton**	**Filamentous Algae**	**Periphyton**	**Filamentous Algae**
CM1	<10	<10	<10	<10
CM2	<10	<10	<10	<10
CM3	10-35	<10	10-35	<10
QM2	<10	<10	<10	<10
GM1	<10	<10	<10	<10
GM2	<10	<10	<10	<10
GM3	<10	<10	<10	<10

3.4 Benthic macroinvertebrates

The relative abundance of habitat disturbance and poor water quality tolerant Oligochaeta (SIGNAL score 2), Diptera excluding Chiromonidae (SIGNAL score 3) and Chironomidae (SIGNAL score 3) was greatest at sites CM3 and CT3 (Fig. 5). Generally, the relative abundance of habitat disturbance and poor water quality sensitive Ephemeroptera (SIGNAL 9) in samples was greater at reference sites, particularly GM2, GM3, GT1 and GT2, compared with below dam sites (Fig. 5). Similarly, Plecoptera (SIGNAL 10) were more abundant in samples from reference sites, although sites CM1 (Corin Dam) and CM2 (Bendora Dam) were more similar to reference sites than the other below dam sites (Fig. 5).

The abundance of Trichoptera (SIGNAL 8) in samples was more similar between test and reference sites than Ephemeroptera and Plecoptera (Fig. 5).

Seven of the 13 sites sampled in autumn 2010 received an AUSRIVAS assessment of either significantly impaired (Band B) (including all test sites below dams) or severely impaired (Band C) (Table 10). Site CM2 (Bendora Dam) and site QM2 (Googong Dam) were assessed as being similar to reference (Band A) (Table 10). While, sites CM1 (Corin Dam), CM3 (Cotter Dam) and QM3 (approx. 2km d/s of Googong Dam) were assessed significantly impaired (Band B) (Table 10). Only reference sites GM2, GM3, GT1, and QM1 were assessed as being similar to reference condition (Band A) (Table 10). The Goodradigbee River site GM1 and tributary site GT2 were assessed as a Band X, having more taxa present than expected (Table 10).

All sites below dams on both the Cotter and Queanbeyan Rivers have been impaired since autumn 2008 (at least), with the exceptions of sites CM3 in autumn 2008, CM1 in spring 2009 and QM2 in spring 2009 when they were assessed as being similar to reference (Table 10). Overall, reference sites have remained in better biological condition as assessed by AUSRIVAS, since autumn 2007, although site QM1 and some tributaries have shown some impairment at times (Table 10), which may be a consequence of low or no flow during drought. This is particularly evident at sites GT3 and CT3, which have been dry for prolonged periods since 2006 and do not appear to have fully recovered. Site CT3 has had high loads of fine sediment since the 2003 bushfires which are likely to be affecting the biological condition.

Generally, more macroinvertebrate taxa were collected from Goodradigbee River reference sites compared to sites below dams (Table 11), with most taxa collected at site GM2 (Band A). Least macroinvertebrate taxa were found at sites CM1 (Band B) and CT3 (Band C), followed by CM3 (Band B)(Table 11). Reference sites also had more sensitive taxa (SIGNAL score ≥5) than test sites, although GT3 and CT3 had similar numbers of sensitive taxa to test sites (Table 11). The estimated whole sample abundance was least at site QM2 (Band A), however, several of the taxa collected (SIGNAL score ≥5) in the subsample were sensitive ones (Table 11). While, site GT2 (Band X) had the greatest whole sample abundance (Table 11). The estimated number of macroinvertebrates per sample from site CM3 on the Cotter River was greater than for other Cotter River sites CM1 and CM2 (Table 11).

Site CT3, which had the lowest O/E score was missing 11 of the taxa expected by the AUSRIVAS model (Table 12). The majority of taxa missing from impaired sites had SIGNAL scores of 5 and above (i.e. more sensitive; Table 12). The most additional macroinvertebrate taxa collected during the sample scan process were from the sample collected at site GM3 (Band A) and two of these taxa were assigned high SIGNAL >7 scores (Table 13). Two of these five taxa (Gomphidae and Hydrobiosidae) found in the scan for GM3 were expected to have occurred by AUSRIVAS but missing in the subsample. Gomphidae, which was expected to occur at site QM3 and not collected in subsample, was collected in the scan (Table 13) Other taxa with high SIGNAL scores present in samples when scanned included Telephlebiidae (9) at CM3, GM2, GM3, GT1 and GT2, Eusthenidae (10) at CT1, Philopotamidae (8) at CM2 and QM1 and Corydalidae (7) at CM3 and GT2, although they were not expected to occur at these sites (Table 13).

Most sites below dams were well separated ($R > 0.75$) from reference sites based on the macroinvertebrate community composition, excluding sites QM1 and CT2 which were not well

separated (R = 0.25) from the below dams sites QM2, QM3, CM2 and CM1 (Fig. 6). The macroinvertebrate communities at the two sites downstream of Googong Dam were similar and grouped together in the ordination space (QM2 and QM3) (Fig. 6). On the Cotter River site CM3 was well separated from sites CM1 and CM2 which grouped together (Fig. 6).

Sites on the Cotter and Queanbeyan Rivers differed from sites on the Goodradigbee River and tributaries GT1 and GT2 by having less of the sensitive taxa such as Leptophlebiidae, Gripopterygidae, Conoesucidae, Glossosomatidae and Calamoceratidae (Table 14). Site QM1 upstream of Googong Dam had a higher abundance of sensitive Leptophlebiidae, Hydrobiosidae, Conoesucidae and Gripopterygidae than the two site sites downstream of Googong Dam (QM2 and QM3) (Table 14). Site GT3 had a lower average abundance of sensitive Conoesucidae, Glossosomatidae and Calamoceratidae than the remaining Goodradigbee River and tributary sites (Table 14).

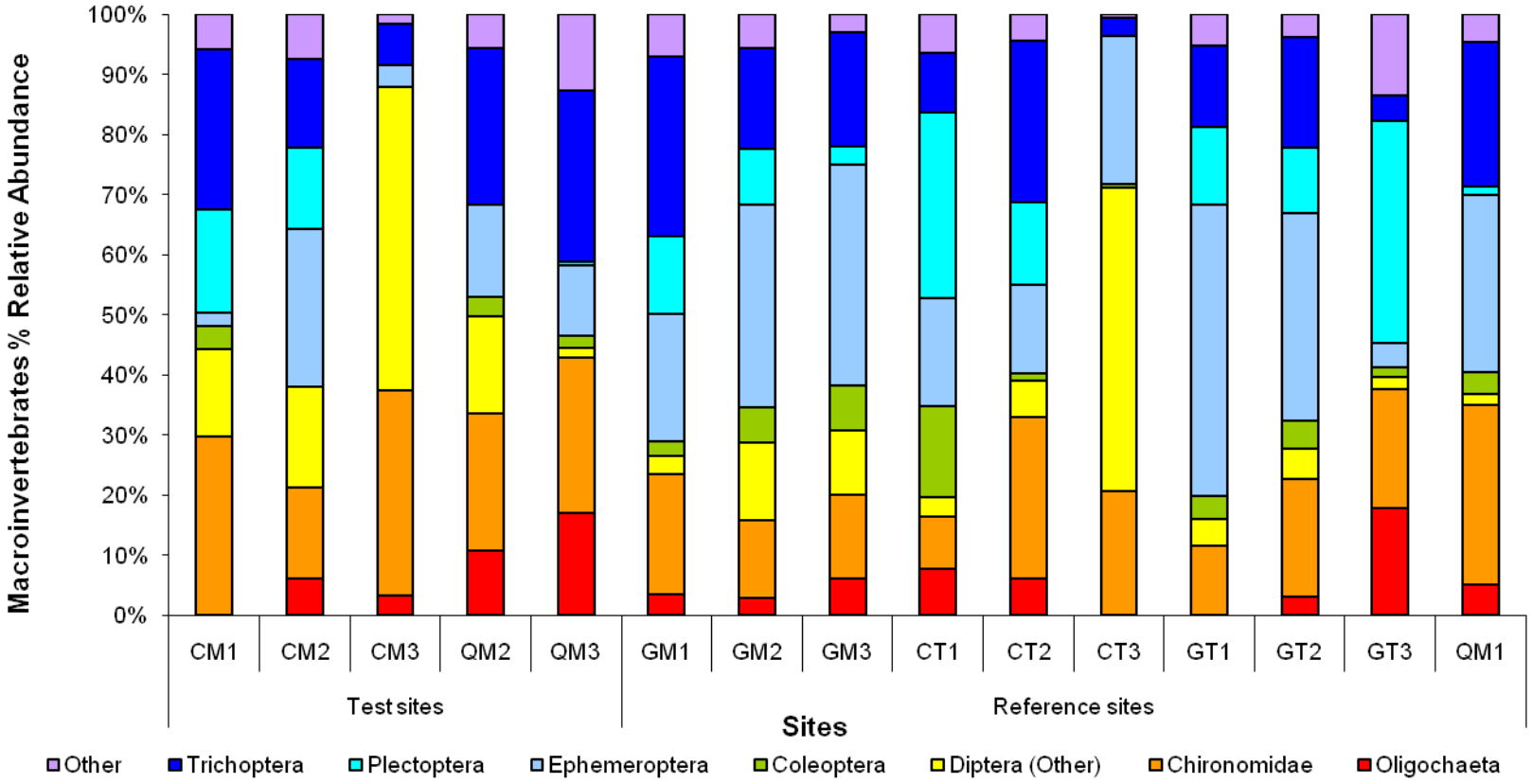

Figure 5: Relative abundance of macroinvertebrates taxa groups (indicated by different colours in the legend) at each sample site; Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), the Goodradigbee River (GM1, GM2, GM3), tributaries of the Goodradigbee River (GT1, GT2, GT3) the Queanbeyan River below Googong Dam (QM2 and QM3) and above Googong Dam (QM1), autumn 2010.

Table 10: AUSRIVAS Model output for the Cotter (CM1, CM2, CM3), Goodradigbee (GM1, GM2, GM3) and Queanbeyan (QM1, QM2, QM3) Rivers and their tributaries, between autumn 2008 and autumn 2010. *Note Band X = more biologically diverse than reference, > 1.13; Band A = similar to reference condition, 0.87-1.13 (spring), 0.88-1.12 (autumn); Band B = significantly impaired, 0.61-0.86 (spring), 0.64-0.87 (autumn); Band C = severely impaired 0.35-0.60 (spring), 0.40-0.63 (autumn); Band D = extremely impaired 0-0.34 (spring), 0-0.39 (autumn), observed and O/E score values are those for taxa with a greater than 50% probability of occurrence. Shading indicates sites that have been assessed as impaired by the AUSRIVAS model.*

	2008		2009		2010	2008		2009		2010
	AUTUMN	SPRING	AUTUMN	SPRING	AUTUMN	AUTUMN	SPRING	AUTUMN	SPRING	AUTUMN
CM1	0.79	0.77	0.86	0.92	0.74	B	B	B	A	B
CM2	0.75	0.82	0.84	0.82	1.04	B	B	B	B	A
CM3	1.04	0.66	0.84	0.66	0.83	A	B	B	B	B
QM2	0.64	0.76	0.77	0.92	0.97	B	B	B	A	A
QM3	0.77	0.72	0.67	0.72	0.83	B	B	B	B	B
GM1	0.99	1.06	1.1	1.14	1.16	A	A	A	X	X
GM2	1.13	0.91	1.12	1.13	1.03	A	A	A	A	A
GM3	1.16	1.16	0.88	1.08	0.92	X	X	A	A	A
QM1	0.81	0.97	0.54	1.16	0.96	B	A	C	X	A
CT1	1.04	1.05	0.93	0.84	0.81	A	A	A	B	B
CT2	0.77	1.01	DRY	0.77	0.77	B	A	DRY	B	B
CT3	0.81	0.83	DRY	0.61	0.58	B	B	DRY	B	C
GT1	1.1	1.01	1.22	1.08	1.01	A	A	X	A	A
GT2	0.9	1.07	0.74	1.22	1.22	A	A	B	X	X
GT3	0.56	0.69	0.41	0.69	0.82	C	B	C	B	B

Table 11: Macroinvertebrate taxa and their sensitivity score (SIGNAL) (Chessman, 2002) collected for taxa identified to family from sub-samples for the Cotter, Goodradigbee and Queanbeyan River sites and their tributaries, sampled during autumn 2010 (*Shading indicates sites that have been assessed as impaired by the AUSRIVAS model.*

CLASS **Order** Family *Subfamily*	**Signal Score**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
							Site									
Tricladida																
Dugesiidae	2		1			1						2				5
BIVALVIA																
Corbiculidae	4														1	8
Gastropoda																
Ancylidae	4		5	2	10	7	1	5	1			1	5		4	
Glacidorbidae	5												1			
OLIGOCHAETA	2		12	10	9	15	12	14	11			10	34	14	23	32
ACARINA	6	11	7	2	4	15	5	6	7	1	7	10	19	13	7	11
INSECTA																
Coleoptera																
Gyrinidae	4					3										
Curculionidae	2												1			
Elmidae (Adult)	7					1		8			1			1		
Elmidae (Larvae)	7	7			3	22	12	17	2	1	4	12	2	9	1	
Psephenidae	6				3	4	3	1			3	2				
Scirtidae	6							2				2			6	4
Diptera																
Athericidae	8					1		3			1					
Ceratopogonidae	4						1	2				1	1		1	
Empididae	5	1	11	1					10		1	3	3	5	2	
Simuliidae	5	26	22	152	4	64	19		1	97	3	10			32	3
Tipulidae	5				4	2	1	1		1	4	3				
Aphroteniinae	8				2	3	4				3	11	1			
Chironominae	3	33	17	54	42	45	5	14	28	17	17	35	29	44	30	27
Orthocladiinae	4	14	6	48	6	14	14	2	19	23	2	10	8	36	14	21
Podonominae	6								1							
Tanypodinae	4	8	7	1	1	5	4		1		2	10		2	5	1

Table 11 cont.

CLASS **Order** Family *Subfamily*	**Signal Score**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
								Site								
Ephemeroptera																
Baetidae	5	3	1	7	18	56	39	1	3	36		9	1	29	15	2
Caenidae	4	1	47	4	29	9	25	7		5	3	23	3	36	17	14
Coloburiscidae	8		2		3	6	3	5								
Leptophlebiidae	8		2		5	104	5	20	24	7	98	84	4	16	1	6
Megaloptera																
Corydalidae	7		1								1					
Odonata																
Gomphidae	5			1	4	6					3		1			
Telephlebiidae	9		1					1								
Plecoptera																
Gripopterygidae	8	32	27		33	48	6	57	25		27	37	71	4		1
Trichoptera																
Calamoceratidae	7				1	2					1	8				
Calocidae	9							1				10				
Conoesucidae	7	25	2		11	22	13	6	24		6	2		1		
Ecnomidae	4		10	2						1				18	15	19
Glossosomatidae	9				3	1	7	1				3				
Hydrobiosidae	8	7	2						4	1	1	3	3	4		
Hydropsychidae	6	13	10	12	38	45	16	3	7	2	10	2	1	30	26	11
Hydroptilidae	4		4	4	6	2		5	4	1		11	3	13	1	3
Leptoceridae	6	4	1		18	6	1				2	5	1		11	21
Odontoceridae	7											5				
Philopotamidae	8			3		9		1	10	1	2	13			3	
Philorheithridae	8										5					
Polycentropodidae	7										1					
Tasimiidae	8							1								
No. individuals		**185**	**198**	**303**	**257**	**518**	**196**	**184**	**182**	**194**	**208**	**337**	**192**	**275**	**215**	**189**
No. of taxa		**14**	**22**	**15**	**23**	**27**	**21**	**24**	**18**	**14**	**24**	**29**	**20**	**16**	**20**	**17**
% of sub-sample		**3**	**3**	**1**	**2**	**2**	**2**	**2**	**2**	**3**	**1**	**1**	**1**	**2**	**7**	**4**
Whole sample estimate		**6166**	**6600**	**30300**	**12850**	**25900**	**9800**	**9200**	**9100**	**6466**	**20800**	**33700**	**19200**	**13750**	**3071**	**4725**

Table 12: Macroinvertebrate taxa missing from the sub-samples in autumn 2010 that were predicted with a ≥50% chance of occurrence by the AUSRIVAS ACT autumn riffle model and their sensitivity score (SIGNAL) (Chessman, 2002). SIGNAL scores are from 1-10, the greatest sensitivity represented by 10. *Shading indicates sites that have been assessed as impaired by the AUSRIVAS model.*

		Site														
Macroinvertebrate	**Signal Score**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Glossosomatidae	**9**								X							
Leptophlebidae	**8**	X		X												
Gripopterygidae	**8**			X												
Hydrobiosidae	**8**			X	X	X	X	X		X					X	X
Elmidae	**7**		X	X						X						X
Corydalidae	**7**									X						
Conoesucidae	**7**			X						X			X			
Scirtidae	**6**	X							X							
Psephenidae	**6**			X					X	X			X			
Podonominae	**6**	X	X	X	X	X	X	X		X	X	X	X	X	X	X
Hydropsychidae	**6**									X						
Leptoceridae	**6**							X	X							
Tipulidae	**5**	X							X				X			
Simuliidae	**5**							X		X			X	X		
Baetidae	**5**									X	X					
Gomphidae	**5**						X			X				X	X	X
Ancylidae	**4**															X
Hydrobiidae	**4**		X			X	X								X	X
Tanypodinae	**4**							X					X			
Caenidae	**4**								X	X						
Coloburiscidae	**4**	X							X							
Hydroptilidae	**4**	X					X				X					
Amphipoda	**3**	X						X								
Oligochaeta	**2**	X									X					
No. of missing taxa		**8**	**3**	**7**	**2**	**3**	**5**	**6**	**7**	**11**	**4**	**1**	**6**	**3**	**4**	**6**

Table 13: Additional macroinvertebrate families and their sensitivity score (SIGNAL) (Chessman, 2002) observed in the visual scan of entire samples from sites on the Cotter River (CM1, CM2, CM3), tributaries of the Cotter River (CT1, CT2, CT3), the Goodradigbee River (GM1, GM2, GM3), tributaries of the Goodradigbee River (GT1, GT2, GT3) and sites on the Queanbeyan River (QM1, QM2 and QM3) in autumn 2010. *Shading indicates sites that have been assessed as impaired by the AUSRIVAS model.*

		Site														
Macroinvertebrate	**Signal Score**	**CM1**	**CM2**	**CM3**	**GM1**	**GM2**	**GM3**	**CT1**	**CT2**	**CT3**	**GT1**	**GT2**	**GT3**	**QM1**	**QM2**	**QM3**
Planorbidae	**2**	**X**														
Physidae	**1**						**X**									
Psephenidae	**6**		**X**										**X**		**X**	
Dytiscidae (larvae)	**2**					**X**										
Ptilodactylidae	**10**							**X**				**X**				
Gyrinidae (larvae)	**4**			**X**												
Parastacidae	**4**									**X**						
Palaemonidae	**4**			**X**										**X**		
Atyidae	**3**									**X**				**X**		
Baetidae	**5**										**X**					
Diamesinae	**6**						**X**									
Corydalidae	**7**			**X**								**X**				
Gomphidae	**5**						**X**					**X**			**X**	**X**
Telephlebiidae	**9**	**X**			**X**	**X**	**X**				**X**	**X**				
Synthemistidae	**2**							**X**								
Eusthenidae	**10**							**X**								
Odontoceridae	**7**										**X**					
Philopotamidae	**8**		**X**											**X**		
Hydrobiosidae	**8**				**X**	**X**	**X**								**X**	
No. of new taxa		**2**	**2**	**3**	**2**	**3**	**5**	**3**	**0**	**2**	**3**	**4**	**1**	**3**	**3**	**1**

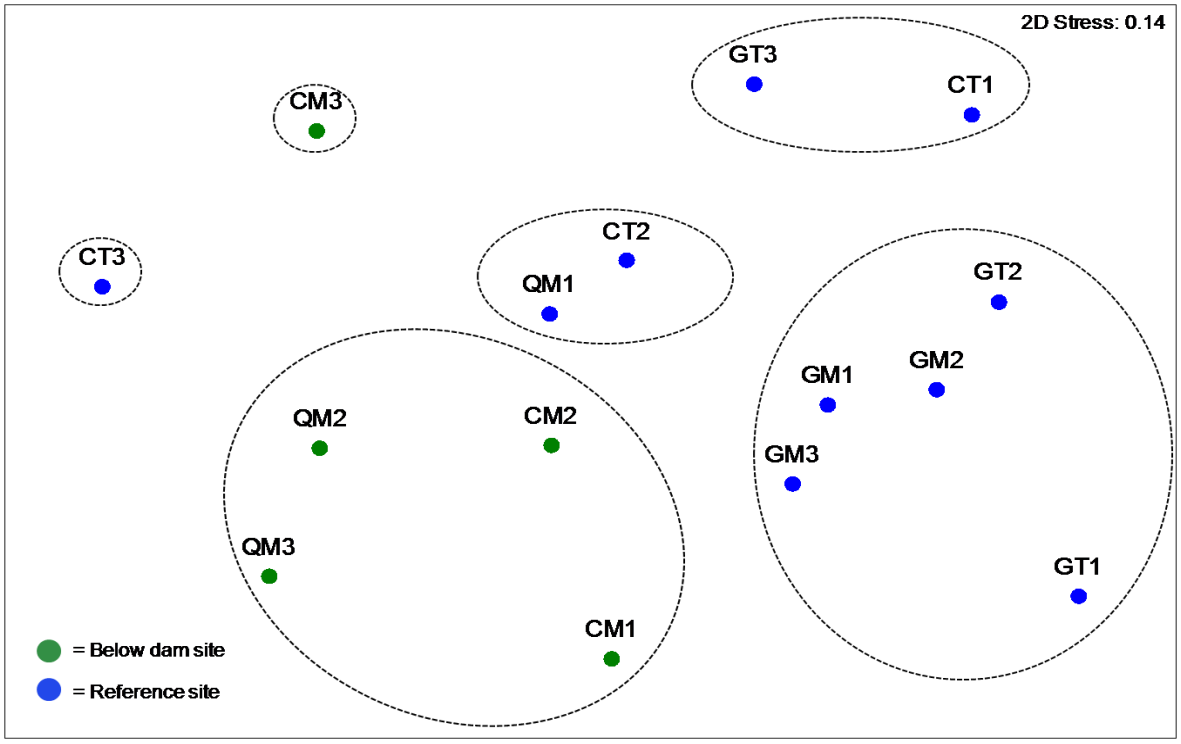

Figure 6: MDS ordination plot of sites below dams on the Cotter and Queanbeyan Rivers and unregulated reference sites on the Goodradigbee River and tributaries, based on similarities in their macroinvertebrate composition (based on abundance) at the family level, autumn 2010.

Table 14: Sensitive macroinvertebrate families (SIGNAL score 7-10: Chessman, 2002) that discriminate between collections from the Cotter, Queanbeyan and Goodradigbee and Queanbeyan River sites from SIMPER analysis. (Note – Average abundance values are based on fourth root transformed values and the larger the consistency ratio (generally >1.4), the more consistent a taxa is as a discriminating taxa).

Taxa	Average Abundance		Consistency ratio
	Cotter and Queanbeyan Rivers (CM1, CM2, QM2, QM3)	*Goodradigbee River (GM1, GM2, GM3, GT1, GT2)*	
Leptophlebiidae	2.08	7.19	1.71
Gripopterygidae	3.36	6.51	1.47
Conoesucidae	2.06	4.87	1.48
Glossosomatidae	0.00	2.93	1.69
Calamoceratidae	0.00	2.86	1.79
	Cotter River (CM3)	*Goodradigbee River (GM1, GM2, GM3, GT1, GT2)*	
Leptophlebiidae	0.00	7.19	2.75
Gripopterygidae	0.00	6.51	6.48
Conoesucidae	0.00	4.87	4.81
Glossosomatidae	0.00	2.93	1.57
Calamoceratidae	0.00	2.86	1.65
	Goodradigbee River (GT3)	*Goodradigbee River (GM1, GM2, GM3, GT1, GT2)*	
Conoesucidae	0	4.87	4.92
Glossosomatidae	0	2.93	1.43
Calamoceratidae	0	2.86	1.64
	Queanbeyan River (QM2, QM3)	*Queanbeyan River (QM1)*	
Leptophlebiidae	2.72	6.51	2.34
Hydrobiosidae	0	3.76	276.82
Conoesucidae	0	2.66	276.82
Gripopterygidae	1.12	3.76	1.66

4 Discussion

4.1 Cotter River and tributaries

Water quality characteristics at sites on the Cotter River and at tributaries were below the recommended ANZECC & ARMCANZ (2000) trigger values, with the exception of where conductivity and turbidity which were slightly below the lower trigger values (Table 7). It should be noted that conductivity and turbidity readings below the lower trigger values will not have an effect on macroinvertebrate communities. Furthermore, measures are representative of the site at the time of sampling and that dissolved oxygen and pH in particular fluctuate through the day depending on temperature and primary productivity (ANZECC & ARMCANZ 2000). Conductivity, turbidity, dissolved oxygen and pH were consistent with previous years research (e.g. White et al. 2009; White et al. 2008; White and Norris 2008b). However, dissolved oxygen concentration at site CM2 was equivalent to the Goodradigbee River and not consistent with the pattern of lower dissolved oxygen patterns in the Cotter River compared to the Goodradigbee River. Whereas, dissolved oxygen concentrations at sites CM1 and CM3 tended to be lower than the Goodradigbee River. Despite this result the dissolved oxygen levels were within the trigger value levels recommended by the ANZECC & ARMCANZ (2000) for maintaining aquatic ecosystem health.

The water quality measurements were all below trigger values at sites CM1 and CT2, which shows improvement from spring 2009 and autumn 2009 respectively (Deschaseaux and Norris 2009, White *et al.* 2009) (Table 8). Ammonia levels were only above the detection limit at sites CM3 and CT1 which is similar to spring 2009. Total Nitrogen concentrations were greater below Cotter Dam (CM3) than at all other test sites and most reference sites except for CT3. Overall, water quality at sites on the Cotter River was poorer than at reference sites, which may have contributed to the impaired macroinvertebrate community. Greater nutrient concentrations are associated with an increase in plant and algal growth, therefore, the high levels of periphyton observed at CM3 and subsequent decomposition, may be a result high nitrate and total nitrogen levels (Figs. 3, 4; Table 8)

The macroinvertebrate communities below dams on the Cotter River were distinctly different from those on the Goodradigbee River and contained a lower abundance of habitat and pollution sensitive taxa (Fig. 6, Table 14). However, only sites below Corin (CM1) and Cotter (CM3) were assessed as being impaired (Band B) by the AUSRIVAS model whereas the site below Bendora Dam (CM2) was considered similar to reference conditions (Band A), which is an improvement in biological condition compared to previous sampling (Table 10). In contrast to sampling in autumn last year (White *et al.* 2009) site CM1 was more impaired than site CM3 with an O/E score of 0.74 versus 0.83 and was in lower biological condition than in 2008 (Table 10)(White and Norris 2008b, White *et al.* 2009). Before spring sampling in 2009, a pool maintenance flow of 550 ML d^{-1} was released one month before sampling and may have contributed to the observed improvement in biological condition (Deschaseaux and Norris, 2009). This type of flow was not released before the 2010 autumn sampling. Also, at sites CM1 and CM2 there were generally less taxa than expected (Table 12). Although the biological condition of the Cotter River sites may have improved downstream of Bendora Dam in terms of the AUSRIVAS O/E score, the Cotter River below the Cotter and Corin Dams was still impaired as indicated by AUSRIVAS (Table 10) and the macroinvertebrate community structure was different at all Cotter River sites with fewer sensitive macroinvertebrate families compared to Goodradigbee River reference sites (Figs. 5 & 6;

Tables 11 and 14). Therefore, it is important to recognise that the flow regime at these sites is likely to have caused to the impaired ecological condition at sites on the Cotter River.

Site CM2 below Bendora Dam has shown some long-term improvement since autumn 2008, with an overall increase in O/E scores to the point where it was equivalent to reference condition (Table 10). However, the overall macroinvertebrate community structure based on abundance was still different from the reference sites on the Goodradigbee River with a lower abundance of taxa with SIGNAL scores ≥7 (Fig. 6; Table 14). Mean AFDM was higher (but not significantly higher because of high variability) at site CM2, which is an indicator of periphyton biomass and organic matter accumulation (Fig. 3). Previously AFDM at this site was reported as significantly higher (White and Norris 2008b). These results indicate that there has been an improvement in biological condition based on the AUSRIVAS O/E score; however, the flows were still insufficient to support a community composition with abundance similar to reference condition.

The AUSRIVAS O/E score for site CM3 downstream of Cotter Dam was similar to the O/E score for Autumn 2009 (White *et al*., 2009) (Table 10). This suggests that the flow regime (a combination of 2 and 20 MLd^{-1}) helped to curb deterioration of the macroinvertebrate community at CM3. Further, before sampling, flows released from the Cotter Dam between 50 and 206 MLd^{-1} was likely to have contributed to maintaining the biological condition of site CM3. However, site CM3 remained impaired (as indicated by AUSRIVAS assessment) relative to reference sites. At site CM3 the Chlorophyll-a content of the periphyton was significantly greater than below Bendora and Corin Dams and there was more cover of periphyton within the riffle and reach compared to other dam sites on the Cotter River (Fig. 4, Table 9). This indicates that there was more active growth of periphyton at site CM1, which had the potential to affect the macroinvertebrate community negatively if the AFDM increased and periphyton smothered the stream bed. Subsequent assessments may determine whether the flow regime will sustain the macroinvertebrate community over time.

The biological condition of all the Cotter River tributary sites was assessed as impaired by the AUSRIVAS model (Bands B and C Table 10). These results are similar to sampling in Spring 2009 with site CT1 and CT3 decreasing in condition indicated by the O/E score (Table 10). Care should be taken in the assessment of tributary sites in the current sampling period, because they were generally more affected by drought than main stream sites. These results suggest that drying in the tributaries over summer may be impairing the macroinvertebrate community at these sites and effecting macroinvertebrate colonisation in the Cotter River.

4.2 Queanbeyan River

All sites on the Queanbeyan River had conductivity, turbidity, pH and dissolved oxygen concentrations either within or slightly below the recommended ANZECC & ARMCANZ (2000) trigger values (Table 7). This indicates that no substantial difference was observed between test and reference sites on the Queanbeyan River in terms of water quality.

Water quality characteristics at reference site QM1 were below the detection limits which was an improvement from autumn 2009 (White *et al.* 2009). Total nitrogen concentrations at sites QM2 and QM3 were above the guidelines, which was similar to spring 2009 (Deschaseaux, E. and Norris, R. 2009) (Table 8). More periphyton cover and AFDM and chlorophyll-a were observed at QM2 compared to below Cotter Dam sites CM1 and CM2 (Figs 3 and 4; Table 8)

but no comparison with any of the reference sites has been conducted for periphyton, which does not allow interpretation.

The macroinvertebrate community at reference site QM1 and test site QM2 (directly downstream of Googong Dam) were assessed by the AUSRIVAS model as being similar to reference (Band A) (Table 10). Only QM3 remained impaired since autumn 2007 (Tingle and Norris 2007; White and Norris 2008b; White et al. 2008; White et al. 2009). Further, even though reference site QM1 had less taxa in total than site QM2, it had the lowest number of expected but missing taxa (Table 11 and 12). Site QM2 had the highest number of taxa and only one more missing taxa than site QM1. Whereas site QM3 had less taxa found in the sample and the greatest number of expected but missing taxa. Site QM1 had a distinctly different macroinvertebrate community structure from sites QM2 and QM3 with a higher abundance of taxa with SIGNAL scores ≥7 (Fig. 5, Table 14). These results show that flows released from Googong dams have been favourable to the macroinvertebrate community directly downstream of the dam (site QM1) in terms of the presence/absence of macroinvertebrate taxa. However, the flows released have not increased the abundance of sensitive taxa such as Ephemeroptera, Plecoptera and Trichoptera compared to upstream of the dam. Also further downstream (site QM3) the flows released from Googong dam have not had as greater effect on the macroinvertebrate community where community composition assessed by AUSRIVAS was not equivalent to reference condition.

All three sites on the Queanbeyan River showed a gradual improvement in condition since autumn 2007 when both QM1 and QM3 were assessed as being severely impaired (Band C) and QM2 as being a Band B (Tingle and Norris 2007; White and Norris 2008b; White et al. 2009). The improvement has been developed from upstream to downstream, QM1, QM2 and QM3 corresponding gradually to a Band X, A and B in spring 2009 (Table 10). However, site QM1 was assessed as Band A and similar to reference with fewer taxa than its previous band X (Table 10). This improvement in condition is likely the result of reduced stress from lower flows (drought) at QM1 in the second half of 2008, which has extended downstream at sites QM2 and QM3. The macroinvertebrates at QM1 still differed from below dam sites QM2 and QM3, indicating that the low flows released to the section of the Queanbeyan River downstream of Googong Dam negatively affected biological condition. Similar to the Cotter River, flows would likely need to be increased to generate the same improvement in the macroinvertebrate community at below dam sites as was found at site QM1 above Googong Dam.

5 Conclusion

Overall, sites below dams along the Cotter and Queanbeyan Rivers were generally more biologically impaired than the reference sites on the Goodradigbee River main channel and tributaries, excluding site GT3. However, all Cotter River tributaries were assessed by the AUSRIVAS model as being in similar or worse condition than test sites on both the Cotter and Queanbeyan Rivers, likely indicating the ongoing effects of low flows and drought conditions. Site CM2 below Bendora is now similar to reference condition as assessed by the AUSRIVAS model. However, overall macroinvertebrate community structure at this site was still distinctly different from reference sites on the Goodradigbee River with a lower abundance of habitat disturbance and pollution sensitive taxa. No substantial changes have been noticed at the Cotter site 100 m upstream of Paddy's River confluence (CM3) and Queanbeyan River site 2km downstream of Googong dam (QM3), indicating a continuing impairment from river regulation when compared to reference sites. Test site QM2 was assessed as being similar to

reference condition, which is a substantial improvement compared to autumn 2007. The improvement of the macroinvertebrate community at the site directly downstream of Googong Dam is likely to have been a consequence of biological recovery from drought conditions. It is difficult to predict if this improvement, which is Queanbeyan River wide, would be temporary or will continue. Current data collected since autumn 2007 suggest that these improvements are independent of flow regime. Continued assessment should clarify the consequence of flow regulation on the macroinvertebrate communities of Queanbeyan River.

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