# Wungong Catchment Trial

## Aquatic Fauna Biodiversity Assessment October 2012

**Final Report**

**13 November 2013**



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## October 2012

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*Frontispiece:* (left to right) Site TA2; measuring water velocity; Vardi Road gauging station.

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## Acknowledgements

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## Recommended Reference Format

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# CONTENTS

## LIST OF FIGURES AND TABLES

### Figures

### Tables

# 1. INTRODUCTION

## 1.1 Background / Objectives

This is the 8th and final survey in a series of annual surveys commissioned by the Water Corporation to assess the effects of the Wungong Catchment Trial (WCT) on the biodiversity of aquatic fauna (principally aquatic macroinvertebrates) in tributary streams of the Wungong catchment. The surveys commenced in December 2005, when the Water Corporation commissioned Wetland Research & Management (formerly the Aquatic Research Laboratory of The University of Western Australia), to develop a monitoring programme to detect changes in aquatic macroinvertebrate assemblages in response to changes in flow regime or water quality conditions associated with the WCT. Subsequent surveys (2006-2012) were undertaken in spring (September-October) when there was greater availability of surface water.

Under the WCT, streams which used to flow all year, but which now flow seasonally due to reduced rainfall and catchment vegetation characteristics, may once again become perennial, and streams that are currently drying may have more secure flows (*i.e*. flow duration in seasonal streams may increase). Perennial streams tend to support greater biodiversity than seasonal streams.

The aquatic monitoring surveys meet the Water Corporation's Key Performance Indicator (KPI) for monitoring stream biodiversity, where the performance measure is "diversity of aquatic macroinvertebrate species" and the performance target is "no statistical change in diversity from the historic range of variability or from the "current reference condition".

To date there has been no evidence that the WCT has affected species richness, abundance or assemblage structure of macroinvertebrate communities. There is however, evidence that macroinvertebrate species assemblages are responding to the drying climate and that this response has not been offset by the WCT.

The current report documents the results of the October 2012 round of aquatic fauna monitoring for the trial.

# 2. METHODS

As in previous monitoring years, changes in biodiversity were assessed by comparing macroinvertebrate and fish communities between streams in treated (exposed) and untreated (control/reference) sub-catchments. Quantitative sampling of aquatic macroinvertebrates was conducted in riffle habitat using a Surber sampler (25 x 25 cm metal quadrat with 250 µm mesh) with 6 replicate samples taken at each site. In conjunction with the fauna sampling, a range of physical and water quality parameters were measured *in-situ* including dissolved oxygen, water temperature, pH, electrical conductivity, water depth and velocity. Qualitative assessment of riparian vegetation and percent cover of dominant substrate (*e.g.* cobble, pebble, gravel, sand, clay, silt, macrophyte, algae) was made by visual assessment. Full details of methods are provided in previous annual reports (Storey & Creagh 2006, 2007, 2008 & 2009).

The design of the sampling programme is based on a Before-After-Control-Impact (BACI) type design. Univariate (ANOVA) and multivariate (ANOSIM) analysis of quantitative replicate samples was used to determine change in macroinvertebrate community structure. Historic data (1984-1990) collected at reference sites in the Canning and North Dandalup catchments were included in analyses to compare how reference sites changed over time relative to their historic condition. ANOVA was performed using IBM SPSS Statistic software (version 19.0 for Windows). ANOSIM was based on similarity matrices (*i.e.*

Bray-Curtis similarity matrices for species data or Euclidean distance matrices for physico-chemical data) generated by the computer program PRIMER version 6 (Clarke & Gorley 2006).

The similarity matrices provide a measure of statistical 'distance' and were used to compare:

i. how impact (exposed) sites changed over time relative to their baseline condition and relative to reference (control) sites, and
ii. how reference (control) sites changed over time relative to their historic (1984-1990) condition.

For example, a Bray-Curtis similarity value of 100% indicated species assemblages were identical, while a value of 0% indicated communities had no taxa in common. ANOSIM was used to test for statistically significant ($p$ <0.05) changes in similarity over time. The expectation was that there would be no change in similarity between the current and future condition of treated sites, if the WCTP effectively offset the reductions in flow associated with climate change.

## 2.1 Sampling Sites

Table 1 provides a list of all sites sampled and locations are indicated in Figures 1A-C. Sites sampled in 2012 included:

- Four sites downstream of treatment areas:
  - TA1, TA2 and Vardi Road, which have been sampled annually since 2005;
  - More Seldom Seen Brook, which has been sampled annually since 2008. The choice of locations for monitoring the impact of upstream treatments on this brook was limited. The only suitable site was one which supported minimal gravel riffle habitat, being located in a very shallow, largely swampy reach upstream of the More Seldom Seen gauging station. As such, data collected from this site are not expected to be the same as data collected from other monitoring sites which are dominated by gravel or cobble riffle runs. It is still important however, to compare and track how this site diverges from / converges with other sites over time.
- Four reference sites:
  - Waterfall Gully, 31 Mile Brook and Foster Brook have been sampled annually since 2005;
  - Wilson Brook, which has been sampled annually since 2007;
  - 39 Mile Brook (Jack Rocks), which has been sampled annually since 2007. Sampling at Jack Rocks was not strictly part of the original WCTP monitoring, but was included to provide data on the effects of fine-scale mosaic burns proposed by DEC. While DEC no longer plan to undertake these trials burns, the aquatic fauna sampling has continued in order to provide additional control/reference data for the WCTP.

**Table 1.** Aquatic fauna sampling sites.

| Site Name (& Code) | Catchment | Stream Order | Site Type | Treatment Area 'Exposure' | Treatment Indicative Status | Sampling Years | Sampling Location | UTM (zone 50) WGS84 | |
|---|---|---|---|---|---|---|---|---|---|
| Waterfall Gully<br>(WF) | Wungong | 1 | Reference | Control | Control catchment, no treatment required | 2005- 2012 | Upstream from road culvert 400m above gauging station. | 413201 E | 6436061 N |
| Treatment Area 1<br>(TA1) | Wungong | 1 | Exposed | WCTP TA1 | Treatment Area 1<br>Total area 2,540ha<br>Available for treatment 1,620ha<br>Treatment already completed 1,070ha | 2005- 2012 | Along Chandler Rd, immediately down-stream of Coronation Rd intersection. | 417987 E | 6428604 N |
| Treatment Area 2<br>(TA2) | Wungong | 1 | Exposed | WCTP TA2 & 3 | Treatment Area 2<br>Total area (TA2): 2 780ha<br>Available for treatment: 1 780ha<br>Treatment completed: 340 ha<br><br>Within TA2:<br>Cobiac cub-catchment -<br>Total area 360ha<br>Available for treatment 260ha<br>Treatment completed 260ha | 2005- 2012 | Pumping Station Rd 300 m upstream of the Coronation Rd bridge. | 419389 E | 6428254 N |
| Vardi Road<br>(VR) | Wungong | 2 | Exposed | WCTP TA1, 2 & 3 | As for TA1 & TA2 | 2005- 2012 | Immediately downstream from gauging station and near 'flying fox'. | 416382 E | 6431737 N |
| More Seldom Seen Brook<br>(MSS) | Wungong | 1 | Exposed | WCTP TA5 | Not yet treated | 2008-2012 | Immediately upstream from gauging station 616022 on More Seldom Seen Brook. | 413350 E | 6431007 N |
| 31 Mile Brook<br>(31MB) | Canning | 1 | Reference/<br>Exposed | Control | No treatment required | 2005-2012 | Off 31 Mile Road; immediately upstream from gauging station. | 420806 E | 6434022 N |
| Jack Rocks<br>39 Mile Brook (JR) | Serpentine | 1 | Reference/<br>Exposed | Control | No treatment required | 2007-2012 | Jack Rocks. Off Kennedia Rd (*via* Balmoral Rd), immediately upstream from gauging station. | 420689 E | 6417649 N |
| Foster Brook<br>(FB) | Nth Dandalup | 1 | Reference | Control | No treatment required | 2005-2012 | Immediately upstream of Sharp Rd culvert, above Nth Dandalup reservoir. | 410324 E | 6403239 N |
| Wilson Brook<br>(WB) | Nth Dandalup | 1 | Reference | Control | No treatment required | 2007-2012 | Off North Road, above Nth Dandalup reservoir. First sampled in 2007 as replacement for 31MB which will be impacted by CSIRO thinning trials. | 410084 E | 6399053 N |

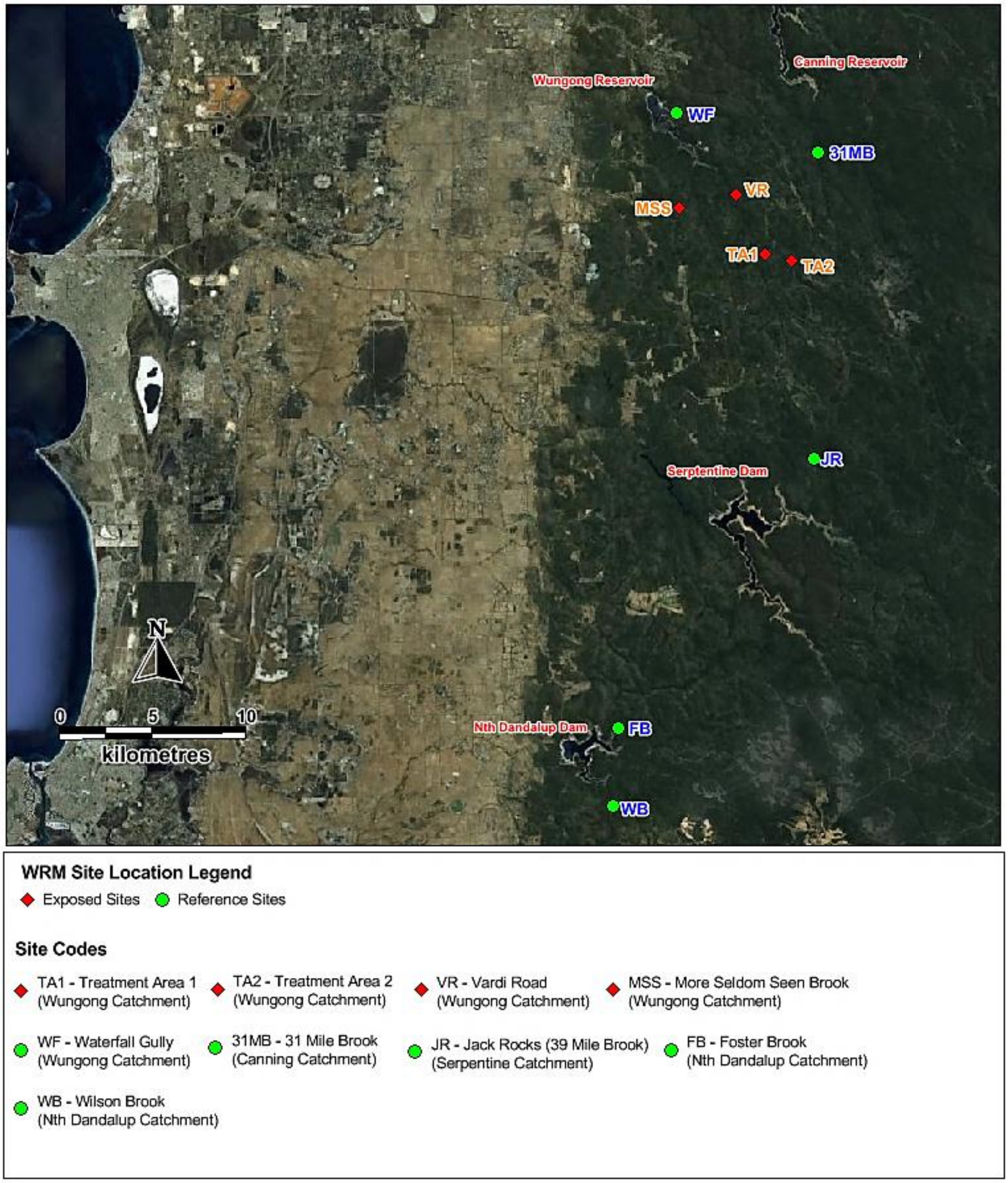

**Figure 1A**. Overview of location of aquatic fauna survey sites within the Canning Catchment, North Dandalup Catchment, Serpentine Catchment, and Wungong catchment.

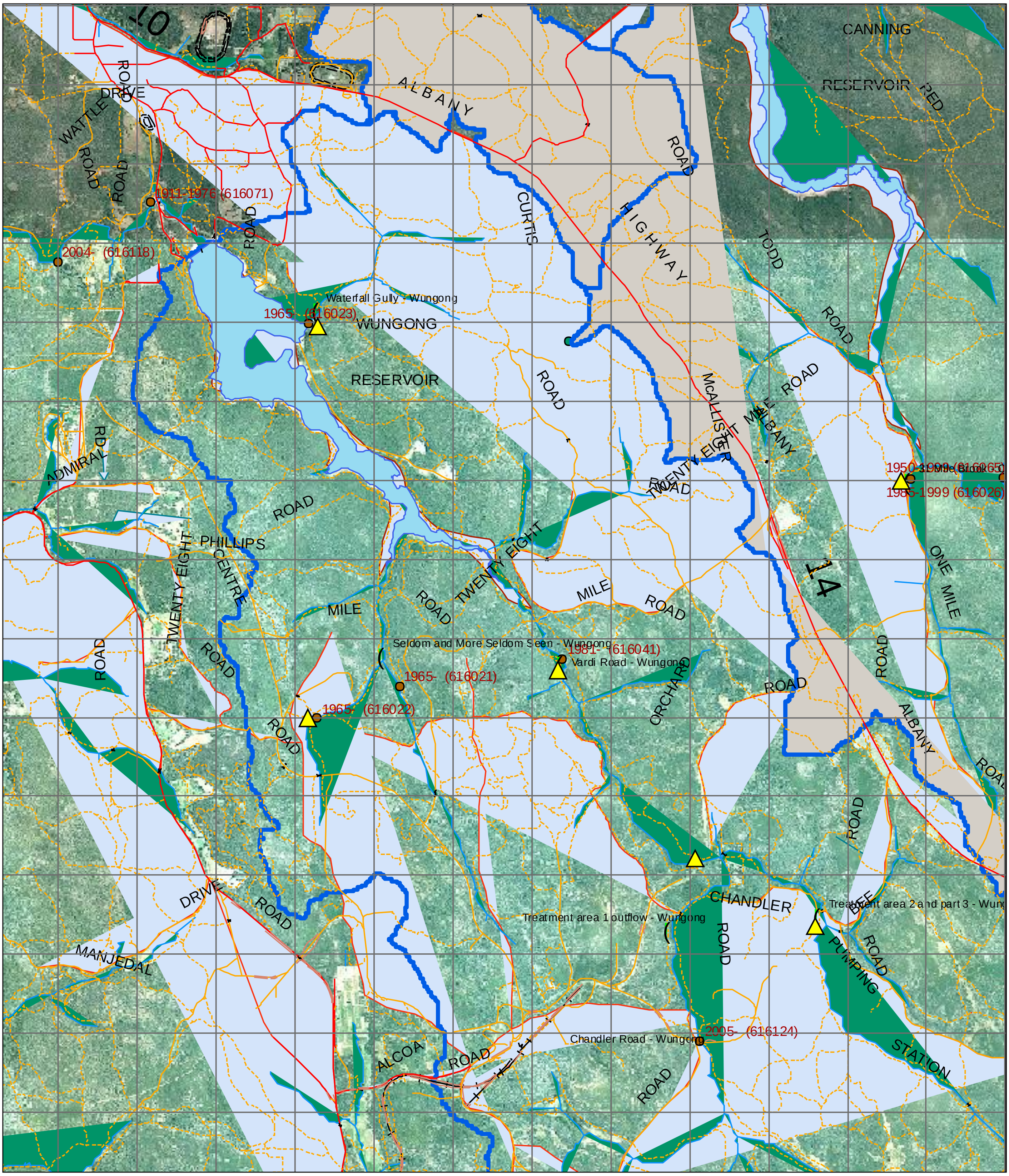

**Figure 1B.** Location of aquatic fauna survey sites (△) within the WCT area and on 31 Mile Brook in the Upper Canning catchment.

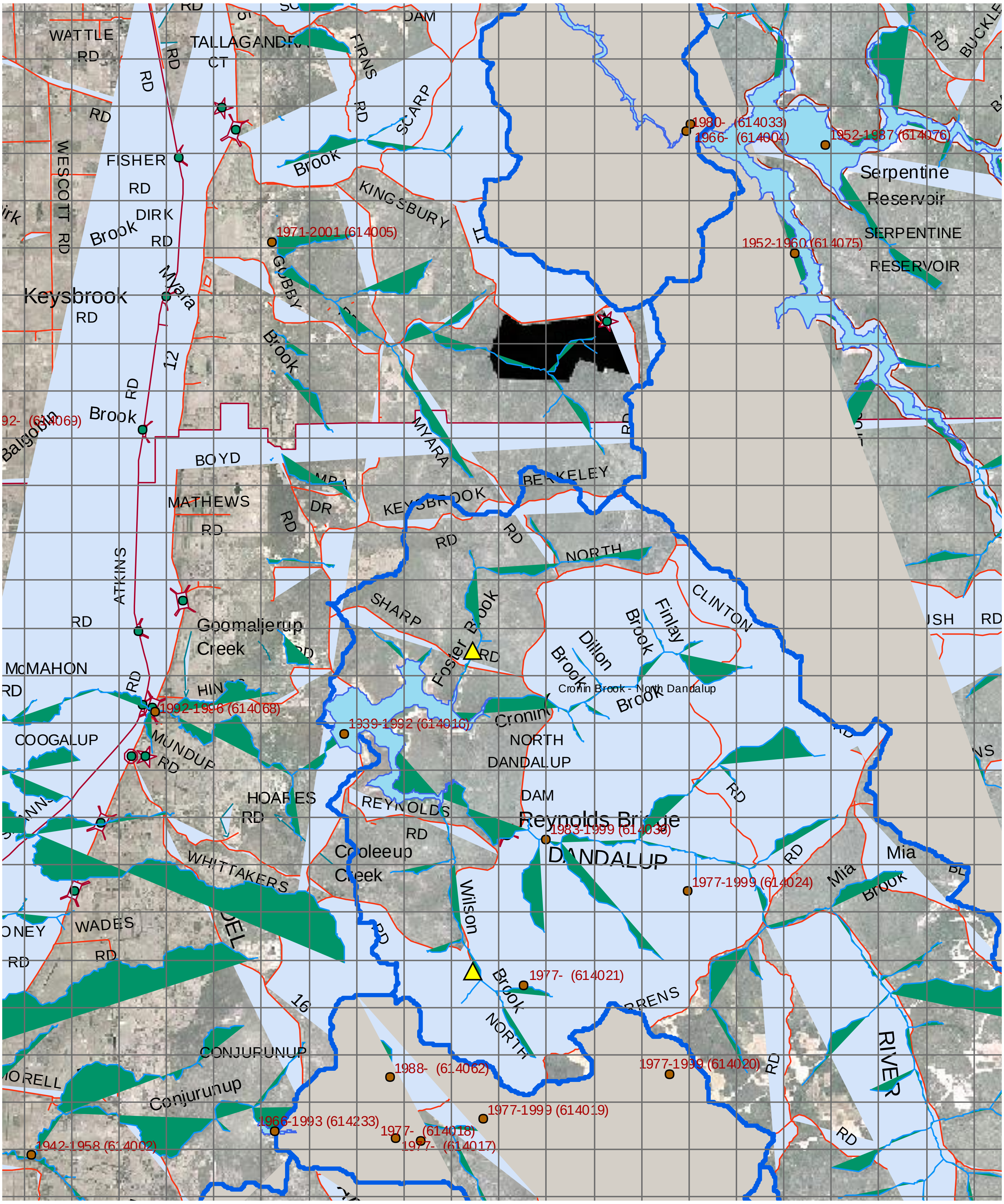

**Figure 1C.** Location of WCT reference (control) sites (△) on Foster Brook and Wilson Brook in the upper North Dandalup catchment.

# 3. RESULTS

## 3.1 Physico-chemistry

As in all prior monitoring years, no detectable changes were observed in riparian vegetation in 2012 (Appendix 1), and water chemistry data for 2012 indicated no significant changes in water quality attributable to the WCT (Table 2 & Appendix 2). While significant temporal differences were found for water quality parameters, these were apparent prior to commencement of treatment; *i.e.* water velocity, electrical conductivity (ECond), dissolved oxygen (DO) and temperature (Table 2). These temporal differences were considered predominantly a reflection of annual and seasonal variations in rainfall, streamflow, ambient air temperature and/or evapo-concentration effects in shallower channels; all unrelated to the WCT. Temporal and spatial variation was also evident across control sites. Examples of changes in water chemistry at individual sites are plotted in Figures 2A-B.

**Table 2.** Summary results from one-way ANOVAs and Tukey's *post hoc* testing for statistical differences in water quality variables between years 2005 - 2012 at each site. Where appropriate, data were log-transformed prior to analyses. Years are arranged in order of highest to lowest annual mean value of the parameter tested. Years joined by a blue line are not significantly (*p*<0.05) different.

| **Variable** | **df** | **F** | ***p*** | **Tukey's Multiple Range HSD Test Year** |
|---|---|---|---|---|
| **Vardi Road** | | | | |
| Velocity | 7, 40 | 10.146 | <0.0001 | 2007 2008 2006 2012 2011 2005 2009 2010 |
| DO% | 7, 40 | 62.459 | <0.0001 | 2007 2008 2006 2012 2011 2005 2009 2010 |
| Temp. | 7, 40 | 524.56 | <0.0001 | 2005 2007 2012 2010 2011 2008 2009 2006 |
| ECond | 7, 40 | 211.73 | <0.0001 | 2006 2005 2008 2007 2011 2009 2012 2010 |
| pH | 7, 40 | 27.868 | <0.0001 | 2006 2008 2012 2005 2007 2011 2009 2010 |
| **TA1** | | | | |
| Velocity | 7, 40 | 25.614 | <0.0001 | 2007 2008 2005 2006 2011 2012 2009 2010 |
| DO% | 7, 40 | 46.802 | <0.0001 | 2008 2007 2006 2012 2005 2011 2010 2009 |
| Temp. | 7, 40 | 269.83 | <0.0001 | 2005 2007 2010 2011 2012 2006 2009 2008 |
| ECond | 7, 40 | 299.93 | <0.0001 | 2010 2012 2006 2005 2011 2008 2007 2009 |
| pH | 7, 40 | 45.712 | <0.0001 | 2006 2008 2012 2005 2011 2010 2009 2007 |
| **TA2** | | | | |
| Velocity | 7, 40 | 22.344 | <0.0001 | 2007 2008 2006 2005 2012 2009 2011 2010 |
| DO% | 7, 40 | 62.459 | <0.0001 | 2007 2008 2006 2012 2011 2005 2009 2010 |
| Temp. | 7, 40 | 524.56 | <0.0001 | 2005 2007 2012 2010 2011 2008 2009 2006 |
| ECond | 7, 40 | 211.73 | <0.0001 | 2006 2005 2008 2007 2011 2009 2012 2010 |
| pH | 7, 40 | 27.868 | <0.0001 | 2006 2008 2012 2005 2007 2011 2009 2010 |
| **Jack Rocks** | | | | |
| Velocity | 5, 30 | 100.29 | <0.0001 | 2007 2012 2011 2009 2008 2010 |
| DO% | 5, 30 | 17.554 | <0.0001 | 2007 2008 2012 2011 2009 2010 |
| Temp. | 5, 30 | 17.041 | <0.0001 | 2012 2010 2011 2009 2007 2008 |
| ECond | 5, 30 | 1.256 | 0.308 | 2008 2009 2011 2007 2010 2012 |
| pH | 5, 30 | 24.809 | <0.0001 | 2008 2007 2009 2011 2012 2010 |

| **Variable** | **df** | **F** | ***p*** | **Tukey's Multiple Range HSD Test Year** |
|---|---|---|---|---|
| **Waterfall Gully** | | | | |
| Velocity | 7, 40 | 29.552 | <0.0001 | 2008 2006 2007 2005 2009 2011 2012 2010 |
| DO% | 7, 40 | 19.39 | <0.0001 | 2010 2006 2009 2007 2012 2008 2011 2005 |
| Temp. | 7, 40 | 326.88 | <0.0001 | 2005 2012 2007 2010 2008 2006 2009 2011 |
| ECond | 7, 40 | 301.84 | <0.0001 | 2011 2012 2007 2009 2005 2006 2008 2010 |
| pH | 7, 40 | 97.999 | <0.0001 | 2006 2012 2005 2008 2010 2009 2007 2011 |
| **31 Mile Brook** | | | | |
| Velocity | 7, 40 | 58.305 | <0.0001 | 2007 2005 2006 2008 2012 2011 2009 2011 |
| DO% | 7, 40 | 25.145 | <0.0001 | 2007 2006 2010 2008 2012 2011 2009 2005 |
| Temp. | 7, 40 | 87.931 | <0.0001 | 2012 2007 2011 2009 2005 2006 2008 2010 |
| ECond | 7, 40 | 1652.8 | <0.0001 | 2005 2006 2012 2010 2011 2008 2009 2007 |
| pH | 7, 40 | 12.451 | <0.0001 | 2008 2006 2012 2005 2007 2011 2010 2009 |
| **Foster Brook** | | | | |
| Velocity | 7, 40 | 14.207 | <0.0001 | 2007 2006 2005 2008 2011 2012 2009 2010 |
| DO% | 7, 40 | 10.704 | <0.0001 | 2007 2010 2012 2006 2011 2005 2008 2009 |
| Temp. | 7, 40 | 24.304 | <0.0001 | 2005 2007 2009 2012 2006 2010 2008 2011 |
| ECond | 7, 40 | 1688.7 | <0.0001 | 2012 2011 2008 2005 2006 2009 2007 2010 |
| pH | 7, 40 | 17.464 | <0.0001 | 2006 2008 2010 2012 2005 2009 2007 2011 |
| **Wilson Brook** | | | | |
| Velocity | 5, 30 | 24.32 | <0.0001 | 2007 2008 2011 2012 2009 2010 |
| DO% | 5, 30 | 25.676 | <0.0001 | 2007 2012 2010 2011 2009 2008 |
| Temp. | 5, 30 | 115.04 | <0.0001 | 2012 2009 2007 2011 2010 2008 |
| ECond | 5, 30 | 16786 | <0.0001 | 2011 2012 2008 2009 2007 2010 |
| pH | 5, 30 | 6.792 | <0.0001 | 2008 2012 2011 2010 2009 2007 |

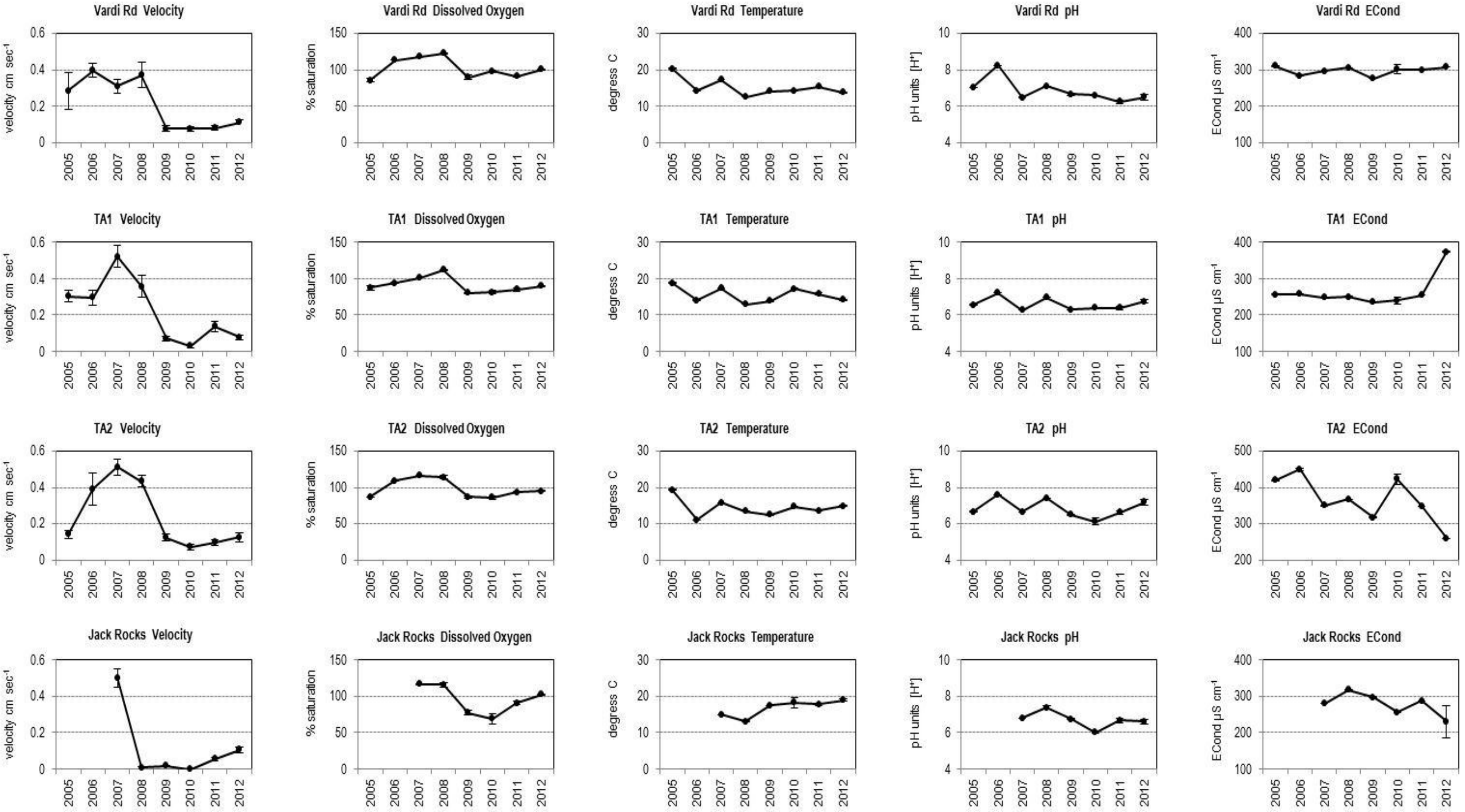

**Figure 2A.** Annual variability in selected physico-chemical parameters (means ± SE) at exposed sites Vardi Road, TA1 and TA2, and at Jack Rocks.

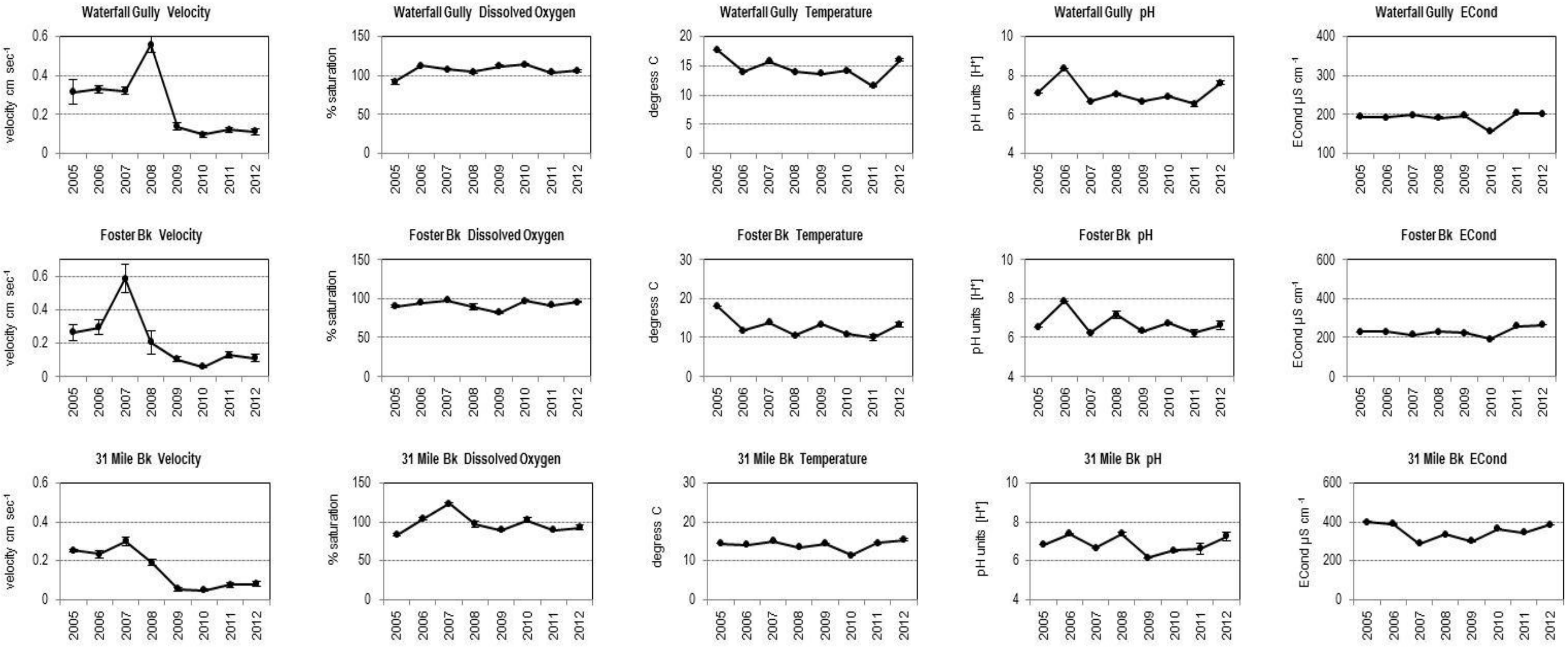

**Figure 2B.** Annual variability in selected physico-chemical parameters (means ± SE) at control (control) sites Waterfall Gully, 31 Mile Brook and Foster Brook.

Since 2005, the most consistent trend across all sites has been a decline in water velocity in 2009, with flows continuing to remain relatively low during the 2010, 2011 and 2012 sampling periods. At most sites, this was accompanied by corresponding fluctuations in DO levels and water temperature, but variable changes in ECond (Figure 2A-B).

Although changes in water quality variables were observed at individual sites, most values remained within the range recommended by ANZECC/ARMCANZ (2000) for the protection of aquatic fauna (Appendix 2). Salinity levels have remained low (ECond <500 µS $cm^{-1}$) at all sites, DO levels moderate to high (70 - 116% saturation) and pH largely within the range of 6 to 8. The exceptions were daytime pH and DO levels at More Seldom Seen Brook in 2011. The pH at More Seldom Seen Brook in 2011 was acidic (5.3) relative to the ANZECC/ARMCANZ (2000) lower guideline limit of pH 6.5, while daytime DO concentration was ~50%, which was low relative to the ANZECC/ARMCANZ (2000) guideline of 90%. Though the DO was relatively low, it was not considered low enough to adversely impact aquatic fauna[1]. The low pH and DO were considered due to higher quantities of organic detritus at this site, which comprised a shallow, narrow ill-defined slow-flowing channel in dense, swampy riparian vegetation with extensive deposits of organic silts.

Analysis of similarity (ANOSIM, based on Euclidean distance) was used to investigate multivariate patterns in physico-chemistry amongst sites. In all years, there were significant differences between exposed sites and control sites (Table 3). However, these differences existed before treatment commenced, and for most exposed sites, the degree to which they differ from control sites has not shown a consistent trend over the monitoring period. In 2012, the greatest difference in water quality between sites was between Vardi Road and Wilson Brook (Table 3).

**Table 3.** Summary results from one-way ANOSIM on 2005-2012 physico-chemical data, comparing exposed sites with control sites. Where R-statistic >0.75 = groups well separated, R-statistic >0.5 = groups overlapping but clearly different, and R-statistic >0.25 = groups barely separable. For all pairwise comparisons, significance level $p$ <0.05.

| Exposed Site | Year | R-statistic for Pairwise Test with Control Site | | | |
|---|---|---|---|---|---|
| | | Waterfall Gully | Foster Bk | 31 Mile Bk | Wilson Bk |
| Vardi Rd | 2005 | 0.656 | 0.687 | 0.778 | -- |
| | 2006 | 1.000 | 1.000 | 1.000 | -- |
| | 2007 | 1.000 | 0.876 | 0.843 | 1.000 |
| | 2008 | 0.963 | 0.878 | 0.854 | 1.000 |
| | 2009 | 1.000 | 0.913 | 0.739 | 0.785 |
| | 2010 | 1.000 | 1.000 | 0.991 | 0.996 |
| | 2011 | 0.993 | 0.774 | 0.428 | 0.754 |
| | 2012 | 1.000 | 0.267 | 0.765 | 0.202 |
| TA1 | 2005 | 0.707 | 0.220 | 1.000 | -- |
| | 2006 | 1.000 | 0.946 | 1.000 | -- |
| | 2007 | 0.852 | 0.561 | 0.950 | 0.926 |
| | 2008 | 0.663 | 0.685 | 0.978 | 0.994 |
| | 2009 | 1.000 | 0.263 | 1.000 | 0.750 |
| | 2010 | 1.000 | 1.000 | 1.000 | 1.000 |
| | 2011 | 1.000 | 0.848 | 0.722 | 0.811 |
| | 2012 | 1.000 | 0.717 | 0.570 | 0.598 |
| TA2 | 2005 | 1.000 | 1.000 | 1.000 | -- |
| | 2006 | 0.707 | 1.000 | 0.707 | -- |
| | 2007 | 0.902 | 1.000 | 0.920 | 1.000 |
| | 2008 | 0.922 | 0.943 | 0.922 | 1.000 |
| | 2009 | 0.976 | 1.000 | 1.000 | 1.000 |
| | 2010 | 0.987 | 0.954 | 0.987 | 0.809 |
| | 2011 | 0.172 | 0.791 | 0.172 | 0.693 |
| | 2012 | 0.750 | 0.287 | 0.750 | 0.172 |
| More Seldom Seen Bk | 2008 | 0.837 | 0.517 | 0.530 | 0.765 |
| | 2009 | 1.000 | 0.643 | 0.713 | 0.680 |
| | 2010 | -- | -- | -- | -- |
| | 2011 | 1.000 | 0.991 | 0.978 | 0.998 |
| | 2012 | -- | -- | -- | -- |
| Jack Rocks | 2007 | 1.000 | 0.804 | 1.000 | 1.000 |
| | 2008 | 1.000 | 0.896 | 0.913 | 1.000 |
| | 2009 | 1.000 | 1.000 | 1.000 | 1.000 |
| | 2010 | 0.956 | 0.941 | 0.956 | 0.800 |
| | 2011 | 1.000 | 0.972 | 0.696 | 0.920 |
| | 2012 | 1.000 | 0.604 | 0.661 | 0.663 |

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[1] DO concentrations less than ~20% typically represent environmental conditions of 'stress' to resident aquatic fauna, particularly fish with high metabolic demand for oxygen.

## 3.2 Macroinvertebrates

A total of 7,148 individuals representing at least 112 taxa were collected from the 9 sites sampled in spring 2012. This was less than the 9,656 individuals from 101 taxa collected in 2011 and the 7, 518 individuals from 95 taxa in 2010 (with taxonomy standardised between years). Based on estimated abundance per $m^{-2}$, this equated to a total 114,368 individuals present in 2012, compared to 154,496 individuals in 2011 and 116,624 present in 2010. In 2012, fauna were dominated by insects (47%), however this was a much lower proportion than in 2011 (81%) and in previous years. The Chironomidae (non-biting midges) were the most dominant insect family, constituting a large proportion (30%) of the total fauna abundance. Oligochaeta (25%) and Crustacea (21%) constituted a greater proportion of fauna in the 2012 survey than in previous years. A systematic list of all macroinvertebrate taxa collected in 2012 is provided in Appendix 3.

Change in macroinvertebrate species richness and abundance in 2012 relative to 2011 was variable across sites. Species richness at exposed sites was comparable to, or higher than that recorded in 2009, 2010 and 2011 (Figure 3A-B). This was also the case for control site 31 Mile Brook and Foster Brook. Increase in species richness was greatest at TA1 where 27% more species were recorded in 2012 than in 2011. Waterfall Gully and Wilson Brook control sites however, showed declines in both species richness and abundance in 2012. There were also large declines in abundance at TA2 (51%[2]) and Foster Brook (45%), relative to 2011. In contrast, species abundance at Vardi Road was similar to that recorded in 2011, while at 31 Mile Brook, abundance recovered by 58% following a large decline in 2011, comparable to abundance data recorded at this site between 2009 and 2010.

Rainfall during winter and spring of 2012 was low in comparison to 2011 (though not as low as 2010) and there was corresponding variability in stream flow (Figure 4). The observed temporal variation in species richness and abundance was also considered a reflection of streamflow patterns. For example, the 2011 decline in species richness at TA1, TA2 and Foster Brook, despite increased streamflow, was likely a lagged response to very low streamflow in 2010. That this was not recorded at other sites possibly reflected a longer period of flow at the other sites. Though flow data were not available for all sites, visual observation suggested longer flow duration at Vardi Road, Waterfall Gully and Wilson Brook, as well as persistence of higher water velocities into late spring/early summer. The relatively large, deeper channel pools at Jack Rocks may also provide summer refuge for many species at this site. In 2012, species richness increased at TA1, TA2 and Foster Brook, but declined at most other sites relative to 2011. Abundances were also generally lower in 2012 than 2011, with the exception of TA1 and 31 Mile Brook.

The numbers of south-west endemics and EPT taxa recorded across control and exposed sites in 2012 were generally higher than in 2011. The exceptions included exposed sites Vardi Road and Jack Rocks, where slight decreases in the number of south-west endemics and EPT taxa were recorded (Figure 3A-B). The greatest decline in EPT taxa was at Waterfall Gully - from 14 species in 2011 and 2010 to only 8 in 2012.

Since 2005, monitoring has revealed statistically significant interannual variation in macroinvertebrate species richness and abundance, both within and between control and exposed groups (Table 4). Similar results were found for whole community structure, based on multivariate analysis (ANOSIM on Bray-Curtis pairwise similarities) of species assemblage data (Tables 5 & 6). In 2012, there were again significant differences in macroinvertebrate assemblages between exposed and control sites. As noted in previous reports, these differences existed before the WCT commenced, and for most exposed sites, the degree to which they differ from control sites has not shown a consistent increasing or decreasing trend over the monitoring period.

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[2] Abundance per $m^2$ calculated from the total number of individuals collected in a 25cm x 25 cm quadrat (area = 0.0625 $m^2$), multiplied by the number of replicate quadrats sampled per site, *i.e*. 6.

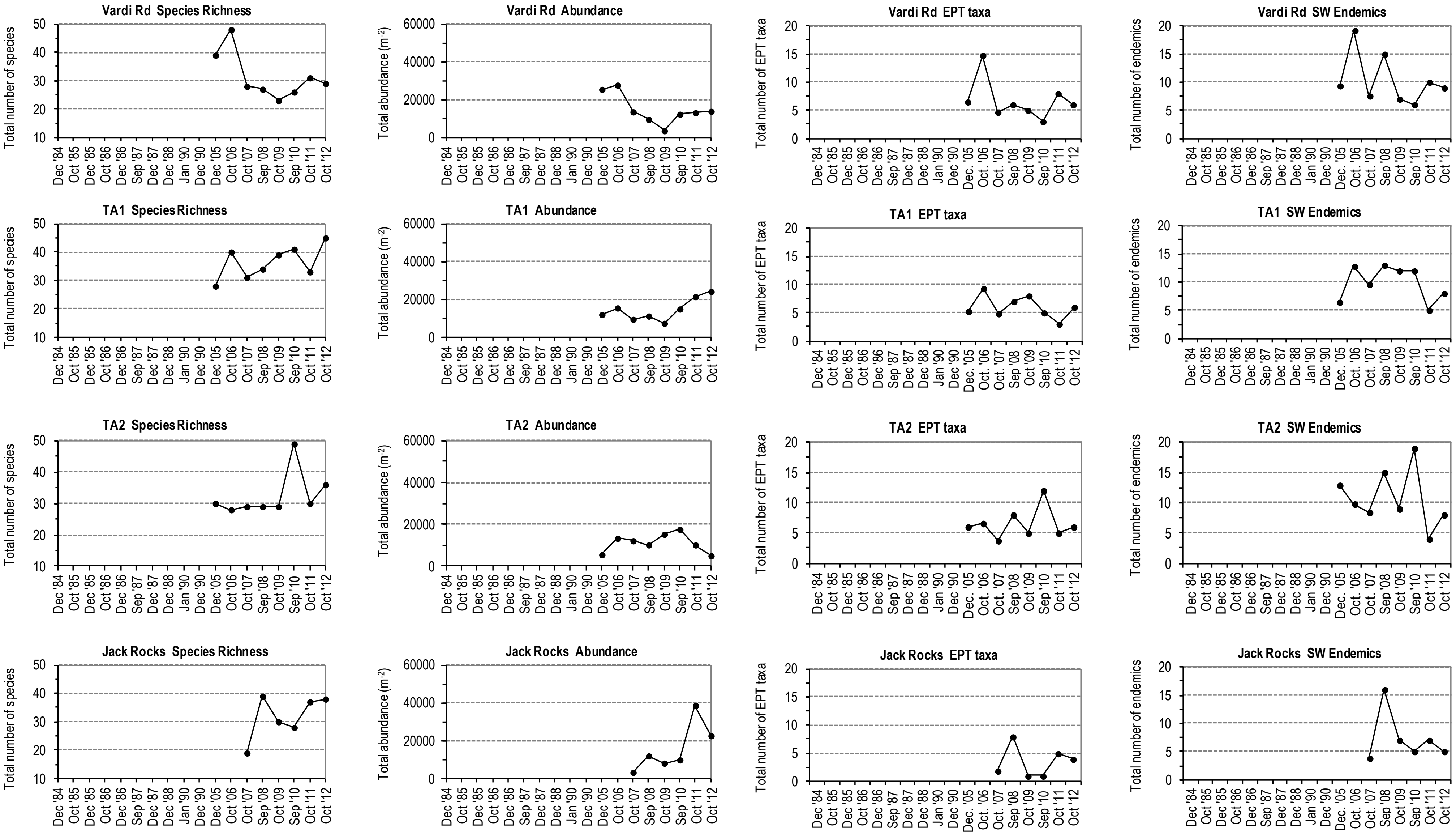

**Figure 3A.** Annual variability in macroinvertebrate species metrics (total richness, total abundance, total number of EPT taxa and total number of south-west endemics) at WCT sites and Jack Rocks. Note: taxonomy has been standardised across years and sampling dates for historic data (1984 -1990) included on x-axes for comparison with reference sites in Figure 3B.

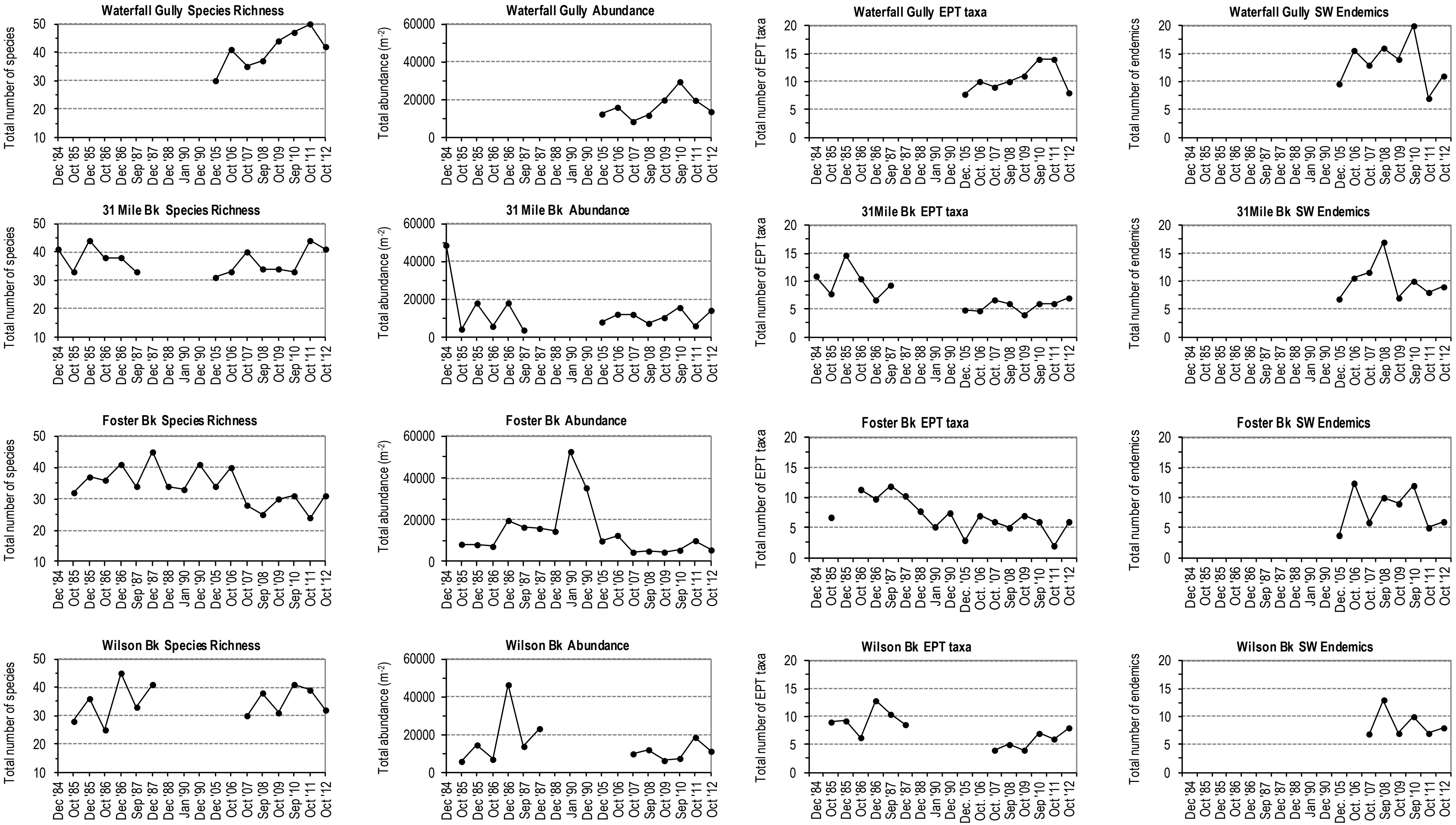

**Figure 3B.** Annual variability in macroinvertebrate species metrics (total richness, total abundance, total number of EPT taxa and total number of south-west endemics) at control (reference) sites. Historic (1984-90) data for reference sites are included for comparison with recent data (2005-11). Note: taxonomy has been standardised across years.

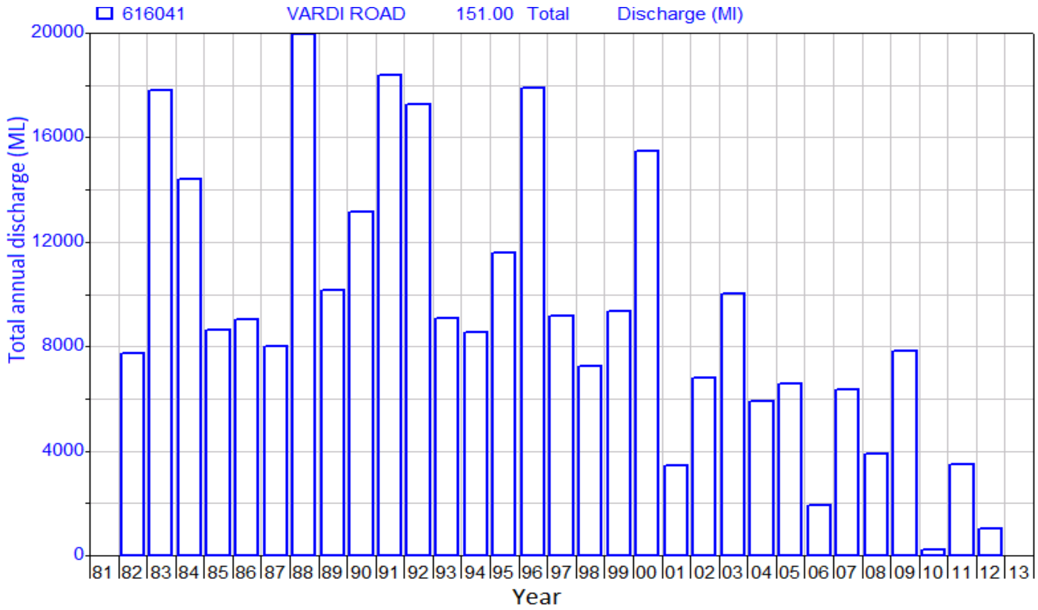

**Figure 4.** Total annual discharge at Vardi Road gauging station (616041) between January 1982 and January 2013 (plot courtesy of Department of Water).

**Table 4.** Summary of results from one-way ANOVA on change in macroinvertebrate species richness (number of species) and log (x+1) transformed abundance ($m^{-2}$) at individual sites over time (2005 - 2012). Significance level *p* value ≤ 0.05; ns = not significant. Where significant differences are indicated, refer to Figures 3A-B to determine which years differ.

| Exposed Sites | | | | | Control Sites | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Site** | **Variable** | **df** | **F** | ***p*** | **Site** | **Variable** | **df** | **F** | ***p*** |
| **Vardi Road** | Richness | 7 | 11.434 | 0.000 | **Waterfall Gully** | Richness | 7 | 3.883 | 0.003 |
| | Abundance | 7 | 5.108 | 0.000 | | Abundance | 7 | 3.842 | 0.003 |
| **TA1** | Richness | 7 | 2.240 | ns | **31 Mile Brook** | Richness | 7 | 1.643 | ns |
| | Abundance | 7 | 2.419 | 0.037 | | Abundance | 7 | 1.510 | ns |
| **TA2** | Richness | 7 | 1.869 | ns | **Foster Brook** | Richness | 7 | 2.538 | 0.029 |
| | Abundance | 7 | 5.164 | 0.000 | | Abundance | 7 | 2.494 | 0.032 |
| **Jack Rocks** | Richness | 5 | 4.728 | 0.003 | **Wilson Brook** | Richness | 7 | 2.739 | 0.037 |
| | Abundance | 5 | 4.630 | 0.003 | | Abundance | 7 | 2.250 | ns |

**Table 5.** Summary results from one-way ANOSIM on log(x+1) transformed macroinvertebrate species abundance data ($m^{-2}$) for 2005-2012, comparing exposed sites with control sites. Significance level $p < 0.05$; ns = not significant. Refer Table 3 for explanation of the R-statistic.

| | | R-statistic for Pairwise Test with Control Site | | | |
|---|---|---|---|---|---|
| **Exposed Site** | **Year** | **Waterfall Gully** | **Foster Bk** | **31 Mile Bk** | **Wilson Bk** |
| **Vardi Road** | 2005 | 0.669 | 0.644 | 0.622 | -- |
| | 2006 | 0.981 | 0.946 | 0.989 | -- |
| | 2007 | 0.772 | 0.811 | 0.607 | 0.82 |
| | 2008 | 0.919 | 0.639 | 0.693 | 0.515 |
| | 2009 | 0.654 | 0.53 | 0.609 | 0.583 |
| | 2010 | 0.994 | 0.607 | 0.906 | 0.683 |
| | 2011 | 1 | 0.73 | 0.578 | 1 |
| | 2012 | 0.804 | 0.398 | 0.541 | ns |
| **TA1** | 2005 | 0.654 | 0.396 | 0.457 | -- |
| | 2006 | 0.972 | 0.583 | 0.922 | -- |
| | 2007 | 0.906 | 0.874 | 0.652 | 0.804 |
| | 2008 | 0.861 | 0.637 | 0.719 | 0.498 |
| | 2009 | 0.422 | 0.474 | ns | ns |
| | 2010 | 0.976 | ns | 0.715 | 0.828 |
| | 2011 | 1 | 0.633 | 0.591 | 0.943 |
| | 2012 | 0.983 | 0.641 | 0.804 | 0.685 |
| **TA2** | 2005 | 0.935 | ns | ns | -- |
| | 2006 | 1 | 0.881 | 0.743 | -- |
| | 2007 | 0.906 | 0.772 | 0.824 | 0.885 |
| | 2008 | 0.819 | 0.683 | 0.63 | 0.535 |
| | 2009 | 0.674 | 0.552 | 0.724 | 0.574 |
| | 2010 | 0.881 | 0.439 | ns | 0.872 |
| | 2011 | 0.922 | ns | 0.522 | 0.846 |
| | 2012 | 0.781 | 0.502 | 0.456 | 0.778 |
| **More Seldom Seen Brook** | 2008 | 0.561 | 0.6 | 0.428 | 0.624 |
| | 2009 | ns | 0.306 | 0.222 | 0.306 |
| | 2010 | -- | -- | -- | -- |
| | 2011 | 0.993 | 0.785 | 0.672 | 0.911 |
| | 2012 | -- | -- | -- | -- |
| **Jack Rocks** | 2007 | 0.919 | 0.931 | 0.863 | 0.861 |
| | 2008 | 0.876 | 0.959 | 0.898 | 0.891 |
| | 2009 | 0.694 | 0.95 | 0.78 | 0.837 |
| | 2010 | 0.965 | 0.893 | 0.961 | 0.883 |
| | 2011 | 0.996 | 0.78 | 0.543 | 0.781 |
| | 2012 | 1 | 0.731 | 0.898 | 0.78 |

Change in pairwise percentage similarity was used to provide a time series analysis of change in spring faunal assemblages at exposed sites relative to their baseline condition (*i.e.* the first spring sampled), and relative to control sites (Figure 5). Similar to the changes in species richness and abundance, there were shifts in whole community structure, *i.e.* shifts in species assemblages. Amongst exposed sites in 2012, Vardi Road and TA1 showed a decline in similarity from both the 2011 condition and the spring 2006 baseline condition (Figure 5). There was little change at TA2 in 2012, though in general, species assemblages at TA2 have shown relatively higher temporal variation (up to 25%) compared to other exposed sites, but this variation has more consistently reflected the average temporal variation recorded across control sites. In contrast, Vardi Road and TA1 have shown less temporal variability in species assemblage composition, but the year-to-year fluctuations have not always mirrored those at control sites. In 2012, both TA1 and TA2 showed a 10% shift further away from control sites.

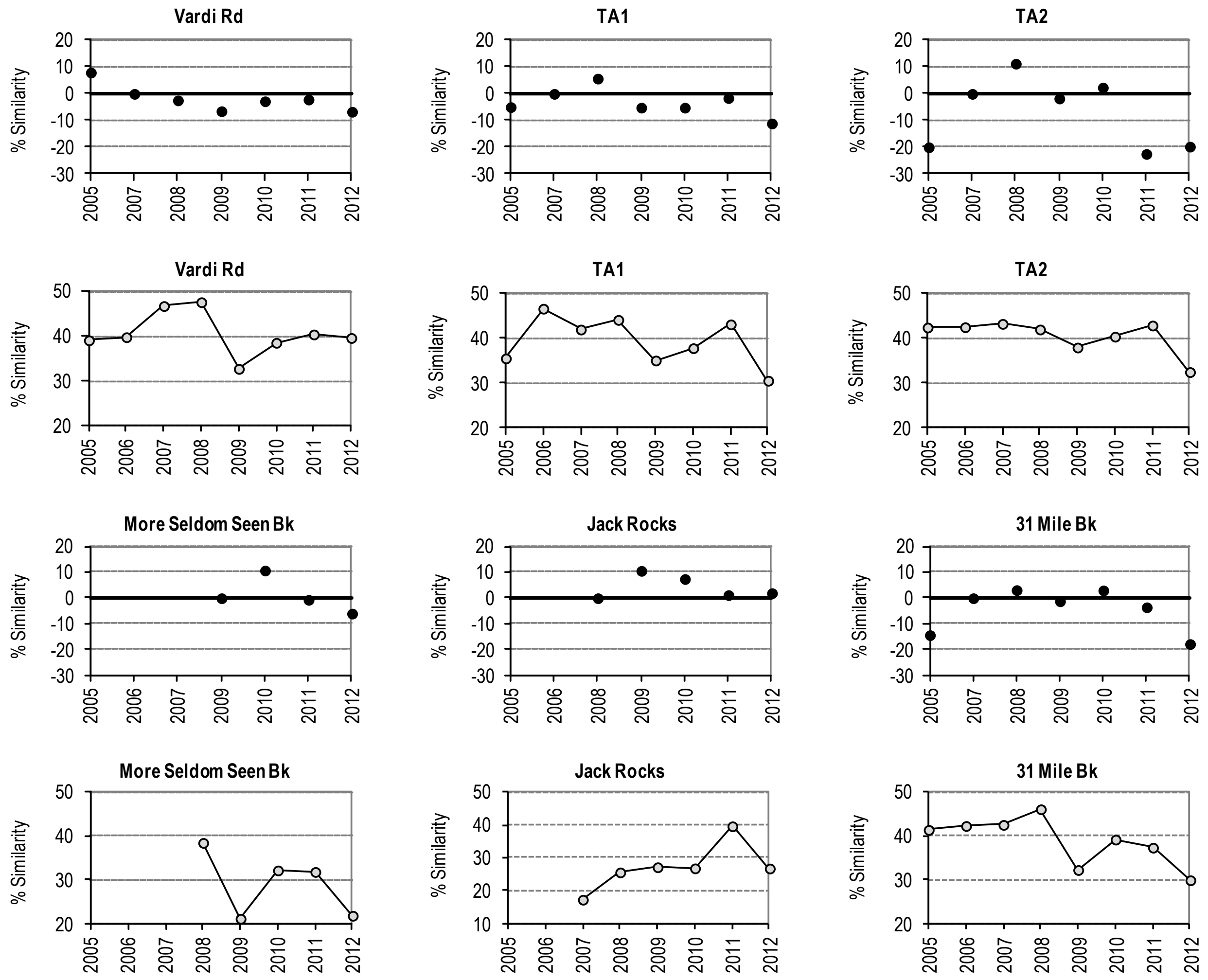

**Figure 5.** Change in similarity of macroinvertebrate species assemblages at individual sites (Vardi Road, TA1, TA2, More Seldom Seen Bk, Jack Rocks & 31 Mile Bk) relative to their baseline condition (● top rows) and their similarity to control sites (○ bottom rows). Baseline condition is indicated as the solid dark line and is based on condition at the time of the first spring sampling; *i.e.* spring 2006 for Vardi Rd, TA1, TA2 and 31 Mile Bk; spring 2007 for Jack Rocks; spring 2008 for More Seldom Seen Bk. All data are percent similarity values determined from pairwise Bray-Curtis distance matrices based on species abundance. As Bray-Cutis similarity increases, similarity between species assemblages increases, *i.e.* the exposed site is becoming more similar to the control sites over time.

A large decline in similarity to the 2006 baseline condition occurred at control site 31 Mile Brook (-18%), which had previously shown only a slight net shift (<10%) away from the 2006 baseline. Taxa contributing most to this shift included paramelitid amphipods, ostracods (seed shrimps) and the leptophlebiid mayfly *Nyungara bunni*, all of which were recorded in higher abundance at this site in 2012 compared to 2006.

The other WCT site sampled, More Seldom Seen Brook, has shown a decline in similarity to control sites over time, with species assemblage composition in 2012 only 22% similar to control sites (Figure 5A). The habitat characteristics of this site are atypical of other exposed sites sampled. The channel is a very small, shallow drainage line that flows through swampy, dense riparian vegetation. Flow is highly seasonal. Water depths during spring sampling occasions have typically been <30cm, and since 2010, the channel has been largely dry. The generally low species richness and abundance at this site, and continuing shift in assemblage composition away from baseline condition were considered a function of an increasingly shortened flow regime and increased frequency of drying.

As in previous monitoring years, 2012 faunal assemblages showed significant spatial variability amongst control sites, as evidenced by ANOSIM tests (see example in Table 6).

Since 2006, there has been a gradual shift in species composition at 31 Mile, Foster and Wilson brooks away from the historic (1985 - 1987) condition. The greatest shift has been at Foster Brook, where similarity to the 1985 condition has declined by 30% (Figure 6).

In general, the temporal changes within reference sites were associated with a trend toward increased abundance of species more common to seasonal and/or slow flowing waters (ostracods, water mites, and paramelitid amphipods), and decreased abundance of taxa more typically associated with higher water velocities and fast-flowing reaches (simulids, baetid mayflies, stoneflies and several midge species).

**Table 6.** Summary results from one-way ANOSIM on log(x+1) transformed macro-invertebrate species abundance data ($m^{-2}$), comparing recent data (2005 -2012) for 31 Mile Brook with (A) recent data from other control sites and (B) with historic (1985-87) baseline data. Significance level *p* <0.05.

| Site | Year | R-statistic for Pairwise Test | | |
|---|---|---|---|---|
| | | Waterfall Gully | Foster Bk | Wilson Bk |
| (A) 31 Mile Bk | 2005 | 0.669 | ns | -- |
| | 2006 | 1 | 0.857 | -- |
| | 2007 | 0.809 | 0.943 | 0.754 |
| | 2008 | 0.885 | 0.693 | 0.557 |
| | 2009 | 0.428 | 0.780 | 0.617 |
| | 2010 | 0.920 | 0.544 | 0.822 |
| | 2011 | 0.894 | 0.765 | 0.606 |
| | 2012 | 0.644 | 0.809 | 0.569 |
| | | 31 MB 1985 | 31MB 1986 | 31MB 1987 |
| (B) 31 Mile Bk | 2005 | 0.583 | 0.769 | 0.863 |
| | 2006 | ns | 0.589 | 0.463 |
| | 2007 | 0.391 | 0.735 | 0.802 |
| | 2008 | ns | 0.637 | 0.515 |
| | 2009 | 0.515 | 0.717 | 0.611 |
| | 2010 | ns | 0.693 | 0.498 |
| | 2011 | ns | 0.742 | 0.627 |
| | 2012 | 0.602 | 0.685 | 0.822 |

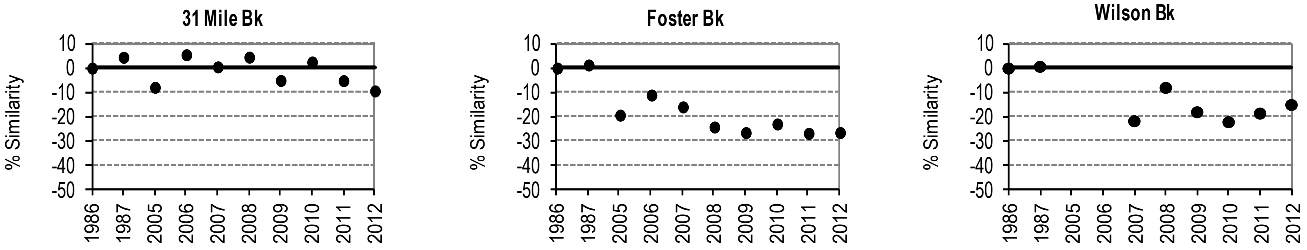

**Figure 6.** Change in similarity of macroinvertebrate species assemblages at control sites 31 Mile Brook, Foster Brook and Wilson Brook, relative to their historic condition. Baseline condition is indicated as the solid dark line and is based on spring data collected in 1985. All data are percent similarity values determined from pairwise Bray-Curtis distance matrices based on species abundance.

Also of note were fluctuations in abundance of paramelitid amphipods. These are obligate groundwater species that require permanent water. Between 2005 and 2010 there was a trend toward declining abundance of these amphipods at TA1 and Vardi Road, though absolute numbers recorded at Vardi Road were low (<15 individuals) in all years. At TA1, there has been a more or less consistent decline, from 158 individuals in 2005, to 6 in 2011 and 7 in 2012. Figure 7 illustrates interannual variation for sites where absolute abundances of >20 have been recorded. Fluctuations in abundance of paramelitids may reflect changes in frequency and/or duration of connectivity between ground and surface waters, or possibly movement and concentration of animals as saturated zones contract in around the main channel.

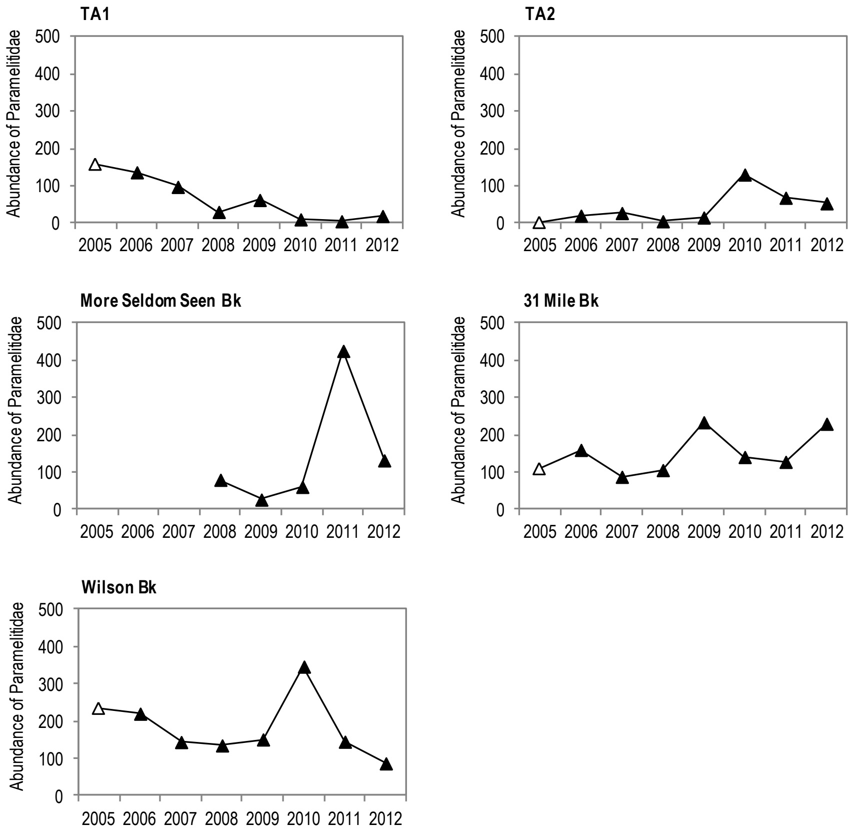

**Figure 7.** Change in absolute abundance of paramelitid amphipods (total number of individuals collected per site) at TA1, TA2, More Seldom Seen Brook, 31 Mile Brook and Wilson Brook.

# 4. DISCUSSION

Based on collective data from monitoring surveys conducted annually between 2005 and 2012, there was no evidence that the WCT reduced the diversity of aquatic macroinvertebrate species. There was however, evidence that macroinvertebrate species assemblages were responding to fluctuations in annual rainfall and streamflow patterns, but that this did not appear to be offset by the WCT.

Temporal change in macroinvertebrate species richness and abundance was variable amongst sites. It was expected that the lower stream discharge in 2012, compared to 2011, would be reflected by lower species richness and abundance in 2012 compared to 2011. Lower abundances were recorded for most sites (except exposed TA1 & control 31 Mile Brook), but species richness was only significantly lower at two sites; control sites Waterfall Gully and Wilson Brook. At other sites, species richness was either higher than or comparable to that recorded in 2009, 2010 and 2011. There were no consistent trends within or between exposed and control groups.

Most notable was the increase in species richness at TA1, where 27% more species were recorded in 2012 than in 2011. There were also large declines in species abundance at TA2 (51%[3]) and Foster Brook (45%), relative to 2011. There was also a decline in EPT taxa at Waterfall Gully; from 14 species in 2011 and 2010 to only 8 in 2012. EPT taxa are those considered most sensitive to environmental disturbance, including changes to flow and water quality. In contrast, total species abundance at 31 Mile Brook recovered by 58% following the large decline observed in 2011. In 2012, total abundance at 31 Mile Brook was comparable to abundances recorded at this site in 2009 and 2010.

Accompanying the temporal changes in species richness and abundance between 2012 and 2011 were changes in species assemblage composition. These were mostly small shifts and mostly due to small decreases in faunal similarity by between 1% and 7%. However, TA1, TA2 and 31 Mile Brook showed relatively large temporal shifts in similarity outside the range observed for previous monitoring years 2005 to 2010. At TA1, similarity to baseline condition (spring 2006) decreased by 11% in 2012, at TA2 similarity decreased by 20% (up from a 22% decline in 2011), and at 31 Mile Brook similarity decreased by 18%. These shifts were due to small (typically <7%) interannual fluctuations in abundance of a large number (up to 20) of species. Taxa contributing most to the overall shift in species assemblages away from baseline condition included gripopterygid stoneflies, the leptophlebiid mayfly *Nyungara bunni*, the synthemistid dragonfly *Austrosynthemis cyanitincta*, hydropsychid caddisflies, black-fly larva (Simulidae) and paramelitid amphipods. Changes in these taxa were considered indicative of changes in flow regime.

At sites for which historic (1985-1990) data were available, comparison with 2012 data suggested a continuing shift away from the historic condition at 31 Mile Brook (Canning catchment) and Foster Brook (North Dandalup catchment). At 31 Mile Brook, similarity of faunal assemblages has shifted away from the pre-1990 condition by 10% over recent years (2006 - 2012), and now more closely resembles summer faunal assemblages rather than faunal assemblages typical of spring. A significantly larger shift was recorded at Foster Brook with a 25% decline in similarity from the pre-1990 condition. A similar decline (22%) was also recorded at Wilson Brook (North Dandalup catchment) in 2010, but in 2011 and 2012 there appeared to be a 7% swing back toward the historic condition. Historically, flow in these three brooks was perennially, but is believed to have become increasingly seasonal since the early 1990s. The change in community structure was considered a response to change in flow permanence at these sites.

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[3] Abundance per $m^2$ calculated from the total number of individuals collected in a 25cm x 25 cm quadrat (area = 0.0625 $m^2$), multiplied by the number of replicate quadrats sampled per site, *i.e*. 6.

Amongst sites, the most consistent responses were, i) decreased abundance of taxa more typically associated with higher water velocities and fast-flowing reaches (*i.e.* simulids, caddis-flies, baetid mayflies, several midge species and the synthemistid dragonfly *Austrosynthemis cyanitincta*), ii) increased abundance of species more common to seasonal and/or slow flowing waters (*i.e.* ostracods, acarines and/or the chironomid *Cricotopus annuliventris*) and iii) increased abundance of gripopterygid stoneflies and the leptophlebiid mayflies (*e.g. Nyungara bunni*). However the magnitude of these changes was highly variable amongst species, sites and years, with individual species contributing less than 10% to the overall change in similarity from historic condition. Some species, such as the stoneflies and leptophlebiid mayflies, may be better able to cope by way of extended periods of egg hatching and the ability to alternate between slow and fast larval development dependent on environmental conditions. The apparent increase in stoneflies and leptophlebiid mayflies at study sites may be a response to changes in stream temperature regime as much as changes in flow regime. Temperature (as well as flow) is known to play a critical role in hatching, larval development and adult emergence (Bunn 1988, Sutcliff *et al.* 2002).

Though not specifically targeted for the WCT, fluctuations in abundance of paramelitid amphipods recorded during the 2005 - 2012 surveys are of interest as they may reflect changes in frequency and/or duration of connectivity between ground and surface waters. Changes in abundance may indicate movement and concentration of amphipods as saturated zones contract around the main channel. As these amphipods are vagrants in surface waters, targeted sampling of groundwater bores would be required to confirm any long-term population trends of these species in groundwaters.

As flow in perennial streams becomes seasonal and flow in seasonal streams becomes episodic, critical thresholds in flow duration needed to allow successful completion of life cycles will be reached, resulting in loss of biodiversity. To date, there has been little research on critical flow duration thresholds in south-west streams and rivers below which species adapted to seasonal (as opposed to episodic) flow regimes would be lost. Faunal response to a drying climate is unlikely to be linear whilst drought refugia, such as permanent pools, persist along the same or adjacent creeks in these catchments. It is possible that more tolerant, cosmopolitan and/or adaptable species may persist even under episodic flow regimes, while more sensitive, less commonly recorded species are lost. This would explain the inconsistencies in temporal and spatial fluctuations observed during the WCT study. The very fact that abundance of sensitive species tends to be inherently variable, coupled with the resilience of cosmopolitan species, may ultimately limit the ability of monitoring programmes to separate climate change response from ‘background noise’ till an ecological threshold is reached.

It was expected that comparison to historic pre-1990 data would show significant change in aquatic communities associated with the significant reductions in streamflow that have occurred over the intervening years. While the study did demonstrate statistically significant change in species assemblages over the long term (pre-1990 versus post-2005) that was readily interpretable as flow-related, year-to-year fluctuations were more difficult to interpret. It was not possible to identify individual indicator species whose population numbers were directly and consistently correlated to interannual variability in stream discharge. The study highlights the problems associated with monitoring naturally dynamic ecosystems, and emphasises the importance of long-term baseline data sets if monitoring programmes are to forewarn of irreversible change. Irreversible change is likely to be abrupt, and detection of potential early-warning signals will be difficult without adequate temporal-spatial context.

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# APPENDICES

# Appendix 1. Foreshore condition rating.

Foreshore condition and stream environmental ratings based on visual, qualitative methods of Pen & Scott (1995) and WRC (1999). Refer to Storey and Creagh (2006) for descriptions of ratings. NA = not assessed.

| **Site** | **Baseline Foreshore Condition in 2005** | **Baseline Stream Environmental Rating in 2005** | **Condition/Rating 2006 - 2012** | |
|---|---|---|---|---|
| | | | **2006** | **2007 - 2012** |
| Waterfall Gully | A1-2<br>(near 'pristine') | Good | A1-2 / Good | A1-2 / Good |
| Vardi Road | A1-2<br>(near 'pristine') | Excellent | A1-2 / Excellent | A1-2 / Excellent |
| TA1 | A3<br>(soil exposed due to recent burn) | Good | A3 / Good | A3 / Good |
| TA2 | B1-2<br>(local weed infestation) | Good | B1-2 / Good | B1-2 / Good |
| More Seldom Seen | NA | NA | NA | A1-2 / Excellent |
| 31 Mile Brook | A1-2<br>(near 'pristine') | Excellent | A1-2 / Excellent | A1-2 / Excellent |
| Foster Brook | A3<br>(soil exposed due to recent burn) | Moderate<br>(severe burn) | A3 / Moderate<br>(some regrowth) | A2 / Good<br>(strong regrowth) |
| Wilson Brook | NA | NA | NA | A1-2 / Excellent |
| Jack Rocks | NA | NA | NA | A1-2 / Excellent |

## Appendix 2. *In situ* water quality and velocity data recorded at each site in October 2012 in conjunction with aquatic fauna sampling.

| Site | Date | Start Time | Rep. No. | Ave. Velocity m/sec | DO % | DO mg/L | Temp. °C | pH pH units | Econd. uS/cm |
|---|---|---|---|---|---|---|---|---|---|
| Foster Bk | 15/10/2012 | 13:00 | 1 | 12.00 | 91.5 | 7.27 | 15.0 | 7.76 | 264 |
| Foster Bk | 15/10/2012 | | 2 | 73.67 | 99.1 | 6.45 | 12.9 | 6.53 | 264 |
| Foster Bk | 15/10/2012 | | 3 | 69.33 | 98.4 | 8.66 | 10.3 | 6.08 | 264 |
| Foster Bk | 15/10/2012 | | 4 | 15.33 | 94.1 | 7.68 | 14.1 | 6.61 | 263 |
| Foster Bk | 15/10/2012 | | 5 | 44.00 | 94.2 | 7.66 | 13.7 | 6.56 | 264 |
| Foster Bk | 15/10/2012 | | 6 | 50.00 | 94.6 | 7.71 | 13.8 | 6.22 | 264 |
| 31 Mile Bk | 18/10/2012 | 16:00 | 1 | 50.33 | 97.8 | 9.08 | 16.7 | 6.13 | 388 |
| 31 Mile Bk | 18/10/2012 | | 2 | 13.67 | 94.6 | 9.57 | 14.8 | 7.32 | 388 |
| 31 Mile Bk | 18/10/2012 | | 3 | 13.00 | 95.8 | 9.70 | 15.4 | 7.61 | 388 |
| 31 Mile Bk | 18/10/2012 | | 4 | 45.67 | 92.9 | 9.31 | 15.5 | 7.63 | 388 |
| 31 Mile Bk | 18/10/2012 | | 5 | 31.00 | 99.1 | 9.93 | 15.2 | 7.48 | 386 |
| 31 Mile Bk | 18/10/2012 | | 6 | 27.00 | 77.8 | 7.87 | 14.9 | 7.48 | 388 |
| Waterfall Gully | 17/10/2012 | 16:00 | 1 | 36.67 | 104.4 | 10.09 | 16.8 | 7.33 | 202 |
| Waterfall Gully | 17/10/2012 | | 2 | 44.67 | 103.0 | 10.10 | 15.9 | 7.57 | 202 |
| Waterfall Gully | 17/10/2012 | | 3 | 45.00 | 106.0 | 10.44 | 16.1 | 7.87 | 202 |
| Waterfall Gully | 17/10/2012 | | 4 | 17.00 | 112.4 | 10.64 | 15.7 | 7.68 | 202 |
| Waterfall Gully | 17/10/2012 | | 5 | 59.67 | 106.3 | 10.51 | 15.6 | 7.76 | 202 |
| Waterfall Gully | 17/10/2012 | | 6 | 68.67 | 104.1 | 10.51 | 15.7 | 7.60 | 202 |
| Wilson Bk | 17/10/2012 | 12:30 | 1 | 16.33 | 97.6 | 10.26 | 12.7 | 6.13 | 282 |
| Wilson Bk | 17/10/2012 | | 2 | 6.67 | 90.9 | 9.49 | 12.9 | 7.74 | 281 |
| Wilson Bk | 17/10/2012 | | 3 | 5.00 | 92.9 | 9.43 | 14.4 | 7.95 | 281 |
| Wilson Bk | 17/10/2012 | | 4 | 34.33 | 94.1 | 9.65 | 14.9 | 6.89 | 279 |
| Wilson Bk | 17/10/2012 | | 5 | 48.67 | 92.9 | 9.53 | 13.7 | 6.25 | 281 |
| Wilson Bk | 17/10/2012 | | 6 | 26.33 | 93.4 | 9.78 | 13.2 | 6.81 | 281 |
| TA1 | 16/10/2012 | 9:00 | 1 | 21.67 | 91.3 | 9.24 | 14.6 | 7.13 | 374 |
| TA1 | 16/10/2012 | | 2 | 10.67 | 88.2 | 9.22 | 13.8 | 6.61 | 374 |
| TA1 | 16/10/2012 | | 3 | 16.67 | 91.1 | 9.40 | 14.3 | 6.58 | 373 |
| TA1 | 16/10/2012 | | 4 | 44.00 | 92.1 | 9.40 | 14.3 | 6.65 | 373 |
| TA1 | 16/10/2012 | | 5 | 46.00 | 89.1 | 9.17 | 13.9 | 6.63 | 374 |
| TA1 | 16/10/2012 | | 6 | 25.33 | 88.2 | 9.07 | 13.9 | 6.87 | 371 |
| TA2 | 16/10/2012 | 11:25 | 1 | 115.33 | 98.4 | 7.54 | 15.2 | 7.24 | 261 |
| TA2 | 16/10/2012 | | 2 | 31.33 | 97.1 | 7.85 | 14.2 | 6.60 | 261 |
| TA2 | 16/10/2012 | | 3 | 54.00 | 95.5 | 9.61 | 15.6 | 7.27 | 261 |
| TA2 | 16/10/2012 | | 4 | 39.00 | 92.3 | 9.58 | 14.8 | 7.29 | 261 |
| TA2 | 16/10/2012 | | 5 | 51.00 | 93.8 | 9.46 | 15.2 | 7.83 | 262 |
| TA2 | 16/10/2012 | | 6 | 31.67 | 94.3 | 9.55 | 14.7 | 7.06 | 261 |
| Vardi Rd | 18/10/2012 | 10:00 | 1 | 29.33 | 100.7 | 10.38 | 14.0 | 7.10 | 308 |
| Vardi Rd | 18/10/2012 | | 2 | 41.00 | 102.9 | 10.89 | 13.6 | 6.78 | 308 |
| Vardi Rd | 18/10/2012 | | 3 | 20.00 | 101.5 | 10.62 | 13.6 | 6.61 | 308 |
| Vardi Rd | 18/10/2012 | | 4 | 72.33 | 102.2 | 10.66 | 13.6 | 6.36 | 308 |
| Vardi Rd | 18/10/2012 | | 5 | 66.33 | 97.4 | 10.28 | 13.8 | 6.24 | 308 |
| Vardi Rd | 18/10/2012 | | 6 | 45.00 | 100.8 | 10.40 | 14.0 | 6.00 | 308 |

| Site | Date | Start Time | Rep. No. | Ave. Velocity m/sec | DO % | DO mg/L | Temp. °C | pH pH units | Econd. uS/cm |
|---|---|---|---|---|---|---|---|---|---|
| Jack Rocks | 15/10/2012 | 17:00 | 1 | 38.33 | 104.2 | 7.60 | 19.8 | 7.15 | 273 |
| Jack Rocks | 15/10/2012 |  | 2 | 20.33 | 104.2 | 7.49 | 19.6 | 6.78 | 274 |
| Jack Rocks | 15/10/2012 |  | 3 | 33.67 | 102.2 | 7.37 | 19.5 | 6.48 | 8.7 |
| Jack Rocks | 15/10/2012 |  | 4 | 72.00 | 101.6 | 9.42 | 19.0 | 6.13 | 276 |
| Jack Rocks | 15/10/2012 |  | 5 | 62.00 | 100.9 | 9.40 | 18.5 | 6.41 | 275 |
| Jack Rocks | 15/10/2012 |  | 6 | 29.33 | 101.4 | 10.11 | 17.2 | 6.70 | 274 |
| More Seldom Seen Bk | 18/10/2012 | 13:00 | 1 | 25.67 | 66.4 | 6.34 | 13.7 | 5.28 | 297 |
| More Seldom Seen Bk | 18/10/2012 |  | 2 | 5.00 | 66.4 | 6.73 | 13.6 | 5.23 | 297 |
| More Seldom Seen Bk | 18/10/2012 |  | 3 | 17.67 | 69.8 | 7.15 | 14.1 | 5.44 | 300 |
| More Seldom Seen Bk | 18/10/2012 |  | 4 |  |  |  | DRY |  |  |
| More Seldom Seen Bk | 18/10/2012 |  | 5 |  |  |  |  |  |  |
| More Seldom Seen Bk | 18/10/2012 |  | 6 |  |  |  |  |  |  |

## Appendix 3. Combined raw abundance data for macroinvertebrate taxa for each site sampled in October 2012.

| Phylum/Class/Order | Family/Species | TA1 | TA2 | Vardi Rd | More Seldom Seen Brook | Waterfall Gully | 31 Mile Brook | Foster Brook | Wilson Brook | Jack Rocks |
|---|---|---|---|---|---|---|---|---|---|---|
| NEMATODA | Nematoda spp. | 156 | 8 | 6 | 13 | 18 | 11 | 12 | 21 | 96 |
| PLATYHELMINTHES | Turbellaria spp. | 1 | 1 | 0 | 0 | 0 | 5 | 15 | 1 | 0 |
| CNIDARIA | *Hydra* spp. | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 3 |
| ANNELIDA | Oligochaeta spp. | 202 | 42 | 222 | 12 | 388 | 149 | 133 | 324 | 280 |
| GASTROPODA | **Lymnaeidae** | | | | | | | | | |
| | *Bullastra vinosa* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | **Glacidorbidae** | | | | | | | | | |
| | *Glacidorbis occidentalis* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Planorbidae** | | | | | | | | | |
| | Planorbidae sp. (imm/dam.) | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| CRUSTACEA | | | | | | | | | | |
| AMPHIPODA | Amphipoda spp. (imm/dam.) | 18 | 17 | 12 | 78 | 64 | 192 | 1 | 1 | 0 |
| | **Paramelitidae** | | | | | | | | | |
| | *Uroctena* spp. | 2 | 37 | 7 | 54 | 23 | 38 | 0 | 0 | 0 |
| | **Perthiidae** | | | | | | | | | |
| | *Perthia acutitelson* | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 |
| | *Perthia branchialis* | 35 | 3 | 16 | 2 | 0 | 0 | 3 | 15 | 13 |
| DECAPODA | **Parastacidae** | | | | | | | | | |
| | *Cherax quinquecarinatus* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CLADOCERA | Cladocera spp. | 175 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 67 |
| COPEPODA | Calanoida spp. | 20 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | Cyclopoida spp. | 8 | 1 | 7 | 1 | 0 | 0 | 0 | 3 | 26 |
| | Harpacticoida spp. | 25 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| ISOPODA | **Scyphacidae** | | | | | | | | | |
| | *Haloniscus* sp. | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| OSTRACODA | Ostracoda spp. | 201 | 4 | 9 | 0 | 0 | 121 | 0 | 5 | 188 |
| ARACHNIDA | Hydracarina spp. | 8 | 11 | 16 | 12 | 5 | 0 | 3 | 0 | 34 |
| COLLEMBOLA | Entomobryoidea spp. | 0 | 1 | 0 | 4 | 1 | 1 | 0 | 0 | 0 |
| | Poduroidea spp. | 0 | 0 | 0 | 50 | 0 | 1 | 0 | 0 | 4 |
| INSECTA | | | | | | | | | | |
| EPHEMEROPTERA | Ephemeroptera sp. (imm/dam.) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | **Baetidae** | | | | | | | | | |
| | Baetidae spp. | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 |
| | *Offadens soror* | 0 | 0 | 0 | 1 | 46 | 0 | 0 | 0 | 0 |
| | **Leptophlebiidae** | | | | | | | | | |
| | Leptophlebiidae spp. | 4 | 18 | 15 | 0 | 5 | 50 | 1 | 20 | 1 |
| | *Bibulmena kadjina* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | *Neboissophlebia occidentalis* | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| | *Nousia* sp. AV16 | 5 | 4 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| | *Nyungara bunni* | 1 | 37 | 4 | 0 | 10 | 64 | 0 | 9 | 0 |
| PLECOPTERA | **Gripopterygidae** | | | | | | | | | |
| | Gripopterygidae spp. (imm/dam.) | 0 | 0 | 53 | 0 | 0 | 23 | 0 | 39 | 0 |
| | *Leptoperla australica* | 0 | 20 | 0 | 8 | 0 | 1 | 0 | 0 | 0 |
| | *Newmanoperla exigua* | 0 | 2 | 39 | 0 | 0 | 6 | 2 | 5 | 0 |
| | *Riekoperla occidentalis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 0 |
| ODONATA | Anisoptera sp.(imm/dam) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | Zygoptera spp. (imm/dam) | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 |
| | **Gomphidae** | | | | | | | | | |
| | *Armagomphus armiger* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | **Megapodagrionidae** | | | | | | | | | |

| Phylum/Class/Order | Family/Species | TA1 | TA2 | Vardi Rd | More Seldom Seen Brook | Waterfall Gully | 31 Mile Brook | Foster Brook | Wilson Brook | Jack Rocks |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Archiargiolestes* sp. | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | **Synthemistidae** | | | | | | | | | |
| | *Austrosynthemis cyanitincta* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | **Telephlebiidae** | | | | | | | | | |
| | *Austroaeschna anacantha* | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| MEGALOPTERA | **Corydalidae** | | | | | | | | | |
| | *Apochauliodes cervulus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| HEMIPTERA | **Notonectidae** | | | | | | | | | |
| | Notonectidae spp. | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| COLEOPTERA | Coleoptera sp. (L) | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | **Dytiscidae** | | | | | | | | | |
| | Dytiscidae spp. (L) | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 2 |
| | Bidessini spp. (L) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | *Necterosoma darwini* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | *Necterosoma* spp. (L) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| | *Platynectes* spp. (L) | 9 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 2 |
| | *Sternopriscus* spp. (L) | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 8 |
| | *Tiporus tambreyi* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | **Hydrochidae** | | | | | | | | | |
| | *Hydrochus* spp. | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | **Ptilodactylidae** | | | | | | | | | |
| | Ptilodactylidae spp. (L) | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| | **Scarabaeidae** | | | | | | | | | |
| | Scarabaeidae sp. | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | **Scirtidae** | | | | | | | | | |
| | Scirtidae spp. (L) | 14 | 0 | 4 | 6 | 0 | 8 | 0 | 6 | 0 |
| DIPTERA | **Athericidae** | | | | | | | | | |
| | Athericidae spp. | 0 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 |
| | **Cecidomyiidae** | | | | | | | | | |
| | Cecidomyiidae spp. | 0 | 1 | 0 | 0 | 0 | 2 | 5 | 2 | 0 |
| | **Ceratopogonidae** | | | | | | | | | |
| | Ceratopogoninae spp. | 124 | 4 | 11 | 0 | 32 | 15 | 2 | 5 | 53 |
| | Dasyheleinae spp. | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 2 |
| | **Chironomidae** | | | | | | | | | |
| | Chironomidae spp. (P) | 8 | 2 | 5 | 3 | 1 | 3 | 2 | 7 | 3 |
| | **Aphroteniinae** | | | | | | | | | |
| | *Aphroteniella tenuicornis* | 0 | 0 | 0 | 0 | 21 | 0 | 0 | 0 | 0 |
| | **Chironominae** | | | | | | | | | |
| | *Chironomus* aff. *alternans* | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Cladotanytarsus* sp. (VSC12) | 1 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 |
| | *Cryptochironomus griseidorsum* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | *Polypedilum* sp. (V3) | 0 | 0 | 0 | 1 | 0 | 2 | 2 | 0 | 0 |
| | *Polypedilum watsoni* | 0 | 1 | 0 | 0 | 5 | 116 | 0 | 0 | 0 |
| | *Rheotanytarsus underwoodi* | 0 | 0 | 1 | 0 | 7 | 0 | 0 | 0 | 0 |
| | *Riethia* sp. 1 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 |
| | *Riethia* sp. 2 | 1 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 |
| | *Stempellina* ?*australiensis* | 0 | 0 | 0 | 0 | 2 | 6 | 0 | 0 | 0 |
| | *Tanytarsus* sp. (V6) | 60 | 1 | 5 | 1 | 9 | 6 | 2 | 3 | 100 |
| | **Orthocladiinae** | | | | | | | | | |
| | ?*Gymnometriocnemus* sp. (V44) | 0 | 3 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| | ?*Gymnometriocnemus* sp. (V45) | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | ?*Limnophyes pullulus* | 26 | 4 | 5 | 0 | 0 | 0 | 0 | 2 | 172 |

| Phylum/Class/Order | Family/Species | TA1 | TA2 | Vardi Rd | More Seldom Seen Brook | Waterfall Gully | 31 Mile Brook | Foster Brook | Wilson Brook | Jack Rocks |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Anzacladius* sp. (V31) | 2 | 0 | 0 | 2 | 0 | 0 | 1 | 6 | 1 |
| | *Botryocladius bibulmun* | 0 | 0 | 0 | 2 | 16 | 0 | 0 | 0 | 0 |
| | *Corynoneura* sp. (V49) | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Cricotopus parbicinctus* | 355 | 62 | 288 | 0 | 11 | 8 | 120 | 154 | 254 |
| | *Lopescladius* sp. (V35) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 28 |
| | *Nanocladius* sp. (VCD7) | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | Orthocladiinae spp. (V15) | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Orthocladiinae spp. (V59) | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | Orthocladiinae spp. (V61) | 6 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | Orthocladiinae spp. (VSC11) | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | *Parakiefferiella* sp. (VSC9) | 2 | 4 | 0 | 1 | 0 | 0 | 4 | 1 | 0 |
| | *Stictocladius occidentalis* | 0 | 0 | 0 | 0 | 62 | 1 | 0 | 0 | 0 |
| | *Thienemanniella* sp. (V19) | 4 | 5 | 12 | 0 | 5 | 2 | 11 | 5 | 0 |
| | **Tanypodinae** | | | | | | | | | |
| | *Australopelopia prionaptera* | 0 | 1 | 0 | 0 | 15 | 0 | 0 | 0 | 0 |
| | *Larsia ?albiceps* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | *Paramerina ?levidensis* | 12 | 0 | 1 | 1 | 0 | 11 | 8 | 16 | 8 |
| | Pentaneurini sp. (V20) | 0 | 0 | 2 | 0 | 0 | 5 | 3 | 0 | 0 |
| | Pentaneurini sp. (V34) | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| | *Procladius paludicola* | 3 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| | *Procladius villosimanus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29 |
| | **Culicidae** | | | | | | | | | |
| | *Anopheles* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | **Dolichopodidae** | | | | | | | | | |
| | Dolichopodidae sp. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | **Empididae** | | | | | | | | | |
| | Empididae sp. | 1 | 0 | 2 | 0 | 1 | 2 | 1 | 2 | 2 |
| | **Ephydridae** | | | | | | | | | |
| | Ephydridae sp. | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| | **Sciaridae** | | | | | | | | | |
| | Sciaridae sp. | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | **Simuliidae** | | | | | | | | | |
| | Simuliidae spp. | 0 | 2 | 113 | 2 | 39 | 8 | 4 | 12 | 2 |
| | **Stratiomyidae** | | | | | | | | | |
| | Stratiomyidae sp. | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| | **Tabanidae** | | | | | | | | | |
| | Tabanidae sp. | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| | **Tanyderidae** | | | | | | | | | |
| | Tanyderidae sp. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Tipulidae** | | | | | | | | | |
| | Tipulidae sp. | 2 | 0 | 0 | 1 | 6 | 0 | 0 | 0 | 2 |
| TRICHOPTERA | **Ecnomidae** | | | | | | | | | |
| | *Ecnomus* sp. | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| | **Hydropsychidae** | | | | | | | | | |
| | *Smicrophylax australis* | 0 | 0 | 1 | 0 | 14 | 0 | 0 | 0 | 0 |
| | **Hydrobiosidae** | | | | | | | | | |
| | *Taschorema pallescens* | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 |
| | **Hydroptilidae** | | | | | | | | | |
| | Hydroptilidae spp. (imm/dam.) | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| | *Acritoptila* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | *Maydenoptila baynesi* | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 5 |
| | *Maydenoptila* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 5 |

| Phylum/Class/Order | Family/Species | TA1 | TA2 | Vardi Rd | More Seldom Seen Brook | Waterfall Gully | 31 Mile Brook | Foster Brook | Wilson Brook | Jack Rocks |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Leptoceridae** | | | | | | | | | |
| | Leptoceridae spp. | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| | *Triplectides* sp. AV21 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | **Philopotamidae** | | | | | | | | | |
| | *Hydrobiosella michaelseni* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |