Evaluation of the ecological response to large-scale river restoration in the Gellibrand and Carlisle Rivers, western Victoria.

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Executive Summary

Restoration works, in the form of willow management, fencing and replanting of native vegetation has occurred at many sites throughout the Gellibrand Catchment. However, the ecological response of animals in these rivers and streams to such works has not been measured. The Corangamite Catchment Management Authority approached Deakin University to undertake a study to investigate the response of macroinvertebrates and fish to these restoration works as well as gather baseline data on water temperature and light intensity between naturally forested sites and re-vegetated sections of stream.

The aims of this project were to compare forested (natural sites) to those that have had willows removed and restoration works completed (re-vegetated sites) and where restoration works are planned (willow sites). With this design, natural sites represent the target physico-chemical, macroinvertebrate and fish characteristics of an undisturbed environment. Comparisons of natural to re-vegetated sites will indicate if there has been a 'recovery' of the ecosystem toward the target state and the comparison of re-vegetated to willow sites will indicate the degree of change since works were carried out.

Invertebrate and water quality samples were collected from throughout the Gellibrand Catchment during two seasons: Spring 2007 (November 27-29) and Autumn 2008 (April 19-21) with a total of 18 sites sampled each season. Waterways sampled during the study included the Gellibrand River, Carlisle River, Loves Creek & 10 Mile Creek. These 18 sites were divided evenly into three types (Natural, Re-Vegetated and Willow) with six sites of each type. Temperature/light loggers were placed at 8 sites throughout the Gellibrand catchment between February and April 2008, three replicate loggers were placed at each site. Fish populations were sampled once at the native and re-vegetated sites only during January and February.

Water temperatures were higher at re-vegetated sites where works had recently been conducted and cooler in natural forests and long established re-vegetated sites. Light intensity was similar at native forest and eight-year old revegetated sites, and higher in more recently revegetated sites. Invertebrate abundances at each site type showed similar seasonal patterns indicating seasonality has a greater effect on abundance than stream structure or spatial variation in temperature. Assemblages within re-vegetated sites showed little variation compared to natural or willow sites and this may be a response to the disturbance caused by the willow removal process. Over time, as re-vegetated works become established invertebrate assemblages may begin to show the highly variable pattern of assemblages within natural sites. Fish assemblage composition differed between rehabilitated and native forest sites, due to higher abundances of common galaxias (*Galaxias maculatus*) and adult short-headed lamprey (*Mordacia mordax*) and low abundance/absence of river blackfish (*Gadopsis marmoratus*) and mountain galaxias (*Galaxias olidus*) in rehabilitated sites. Low numbers of adult river blackfish and the absence of juvenile river blackfish in this study suggest further sampling is necessary to identify the distribution and abundance of juvenile river blackfish.

Therefore, this study shows that eight year old revegetated sites have similar light and temperature conditions to native vegetation sites. However, the fish and invertebrate fauna do not yet closely resemble those at native vegetation sites. In particular, the invertebrate assemblages are remarkably uniform at revegetated sites, regardless of site age, compared to both willow and native vegetation sites. It is worth noting though, that strong seasonal differences shown by willow and native vegetation sites are also reflected in revegetated sites, demonstrating that seasonal stream processes are occurring at all site types. The revegetated sites within the Gellibrand catchment are therefore becoming more like native vegetation sites in terms of light and temperature conditions and also contain the same, common fish and invertebrate species. However, the revegetated sites have not yet been extensively colonised by two native fish species and they do not display the site-to-site variation seen in undisturbed sites and especially in sites with remnant native vegetation. Over time, they may progress more towards animal assemblages at the native vegetation sites and further sampling will be necessary to determine whether this is the case.

Acknowledgements

We would like to thank the landowners who allowed access to private properties in order to sample the re-vegetated and willow sites. Denis Lovric helped organise the planning of this project and Garry Matherson was valuable as a guide on the initial fieldtrip. Kerrylyn Johnston assisted with fieldwork during the spring and autumn macroinvertebrate sampling trips. Travis Howson is thanked for his help in sorting invertebrate samples as well as putting some of the loggers in place and Dr Edwin Chester provided advice on invertebrate identification and statistical procedures.

Introduction

Willows were introduced to Australia from Europe, Asia and North America and widely planted along streams throughout Victoria, generally to increase bank stability following the loss of native vegetation. Planting became particularly intensive between the 1950's and 70's however willows proved to be highly invasive and it is estimated willows spread across 30 000km of river frontage throughout Victoria (Holland and Davies, 2007; Jayawardana et al., 2006).

While willows provide initial stabilisation of banks, over time they encroach into the stream, cause braiding and mid-stream islands and ultimately lead to increased erosion. Leaf loss during autumn is rapid and dropped leaves are quickly broken down leading to water quality problems, namely reduced dissolved oxygen concentrations (Holland and Davies, 2007). Consequently, streamside willows are being removed across the state with native vegetation replanted in their place.

Restoration works, in the form of willow management, fencing and replanting of native vegetation has occurred at many sites throughout the Gellibrand Catchment. However, the ecological response of rivers and streams to such works has not been measured. The Corangamite Catchment Management Authority approached Deakin University to undertake a study to investigate the response of macroinvertebrates and fish to these restoration works as well as gather baseline data on water temperature and light intensity between naturally forested sites and re-vegetated sections of stream.

The aims of this project were to compare forested (natural sites) to those that have had willows removed and restoration works completed (re-vegetated sites) and where restoration works are planned (willow sites). With this design, natural sites represent the target physico-chemical, macroinvertebrate and fish characteristics of an undisturbed environment. Comparisons of natural to re-vegetated sites will indicate if there has been a 'recovery' of the ecosystem toward the target state and the comparison of re-vegetated to willow sites will indicate the degree of change since works were carried out.

Methods

Field and Laboratory Methodology

Invertebrate samples were collected from throughout the Gellibrand Catchment during two seasons: Spring 2007 (November 27-29) and Autumn 2008 (April 19-21) with a total of 18 sites sampled each season. Waterways sampled during the study included the Gellibrand River, Carlisle River, Loves Creek & 10 Mile Creek. These 18 sites were divided evenly into three types (Natural, Re-Vegetated and Willow) with six sites located within each (See appendix 1 for site coordinates).

Macroinvertebrates were collected using a 10-minute integrated sweep of all habitat types present at each site (macrophytes, leaf packs, substratum, large and small woody debris ect.). Samples were preserved using 90% ethanol before being returned to the laboratory for processing. All invertebrates were identified to the lowest practical taxonomic level and counted. Voucher specimens were also retained.

At each site, water quality (physico-chemical parameters) were measured using a Yeo-Kal Model 611. Prior to each fieldtrip the Yeo-Kal was calibrated as per the manufacturers instructions. Parameters measured included temperature, pH, salinity (ppt), dissolved oxygen (mg/l & % saturation), electrical conductivity (µS/cm) and turbidity (ntu). No pH readings are presented for spring as the probe malfunctioned. Three digital photos were also taken at each site during the spring sampling season.

Temperature/Light loggers were placed at 8 sites throughout the Gellibrand catchment between February and April 2008, three replicate loggers were placed at each site. These loggers were programmed to record temperature (°C) and light (lux) at 10 minute intervals. Four sites were located longitudinally down the Carlisle River beginning within an upstream native forest and progressing downstream to three re-vegetated sites, works on these sites had occurred at three different times with the most recent furthest downstream and getting progressively older in the two upstream sites. The remaining loggers were placed at two sites (one native one re-veg) within the Gellibrand and two sites (one native one re-veg) within Loves' Creek. The native site within the Gellibrand (site TS) was approximately 4km downstream of site 5N

Statistical Methodology

Data collected from the loggers was filtered so that only data collected between 12:00 and 15:00 was included within the analysis. This was carried out as it is most likely site differences in light and temperature would be at a maximum during these times. In addition, it is at these times that the presence of a mature canopy would have the most effect and therefore show the greatest contrast between sites. Biofilm was observed to cover many of the loggers, thereby affecting the light readings. To reduce this influence, analysis of light data was restricted to the first two weeks of collection. Differences between sites for both light and temperature were analysed by a one way ANOVA, light data required a square root transformation to meet the required assumptions.

To compare patterns in invertebrate assemblages between the three site types, multivariate analysis was employed. Ordination plots were created to visually assess patterns in community structure and differences between site type was testing using Analysis of Similarities (ANOSIM) with the Primer 5 software (Clarke, 1993). Species responsible for differences between site types was assessed using the Similarity Percentages (SIMPER) function. Fourth root data transformations were used to balance the dominance of numerically abundant species with rarer species. Variability between sites was tested using the Multi-Variate Dispersion (MVDISP) function which quantifies relative multivariate variability within each group.

Differences in invertebrate abundance and diversity between site types (willows, natural, re-vegetated) and seasons (spring/autumn) were tested using a two way ANOVA, normality was checked using p-plots and heterogeneity examined from plots of residuals.

Fish Sampling

In addition to macro-invertebrates, fish populations were also sampled once at native and re-vegetated sites within the Gellibrand and Carlisle Rivers during January and February. For detailed survey design and methods see the independent report submitted by Travis Howson.

Results

Water Quality

Water quality was good across sites throughout the Gellibrand catchment during both Spring 2007 and Autumn 2008 (Table 1 & 2). An exception was site 12 during spring where dissolved oxygen was below 3mg/L and turbidity was high. Turbidity was generally higher during spring and can be attributed to floods which occurred three weeks prior to this sampling trip. Site 12 was found to be dry during the autumn sampling trip so no data was collected at this site. There was no discernable difference in water quality between the three types (i.e. willows vs revegetation vs native vegetation) of sites.

In-situ Loggers

There was a significant ($F_{7, 23} = 180$; $P < 0.01$) difference in mean temperatures between sites across the Gellibrand catchment. The two sites located within naturally vegetated stretches of stream (site 16N and site 10N) were found to be the coolest, while the warmest site (site 9R) was a re-vegetated sites where works had been carried out 12 months prior and riparian vegetation was providing no shading, although there was some limited shading due to incision and high banks (Figure 1). Sites revegetated for eight years (15R, 3R) were cooler than sites more recently revegetated and showed similar temperatures to naturally vegetated sites (Figure 1).

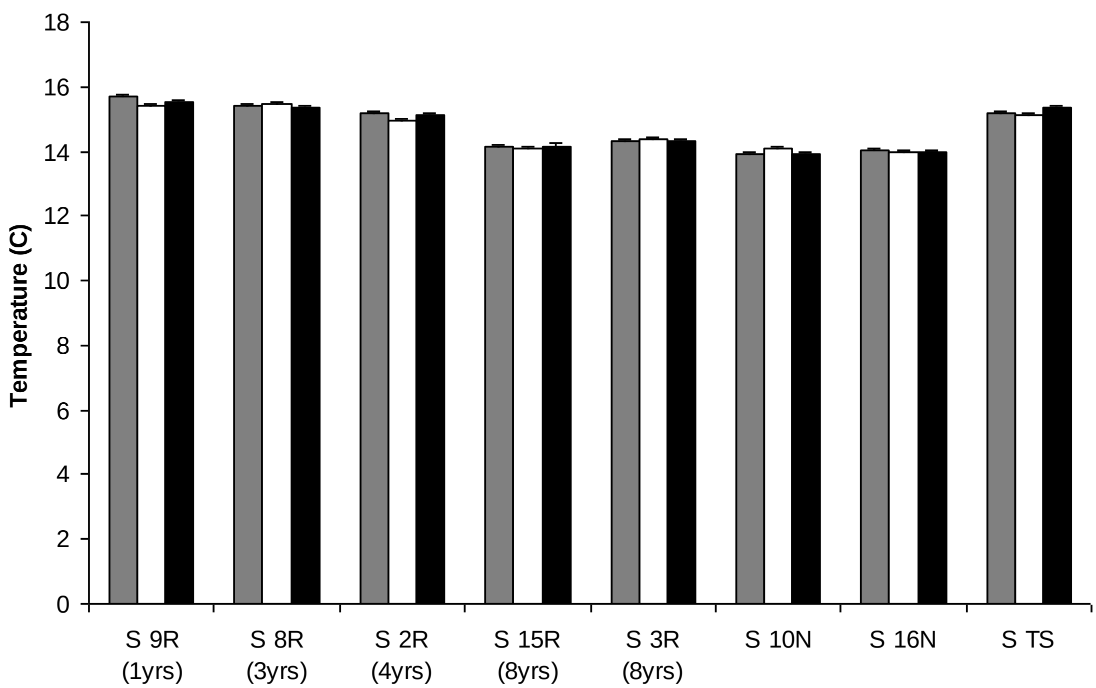

Figure 1. Mean temperature (°C) between 12:00 and 15:00, recorded by the three loggers at each of the eight sites within the Gellibrand catchment during February to April 2008 (+ s.e.)

Site	River	Habitat	Site Code	Time	pH	D.O.%	D.O. mg/L	Turb ntu	Temp.	Cond. µs	Salinity ppt
S1	**Gellibrand**	Willows	S1-W	11:00	n/a	98	10.2	16.5	14.83	0.18	0.09
S2	**Carlisle**	Re-veg	S2-R	12:30	n/a	123.1	13	34.3	14.64	0.13	0.04
S3	**Carlisle**	Re-veg	S3-R	13:20	n/a	139.4	14.4	41.5	13.65	0.09	0.04
S4	**Boggy Creek**	Natural	S4-N	14:50	n/a	132.8	14.1	46.3	11.64	0.1	0.05
S5	**Gellibrand**	Natural	S5-N	16:15	n/a	118.6	11.3	61.8	17.21	0.12	0.06
S6	**Gellibrand**	Natural	S6-N	16:40	n/a	114.5	11.1	21.3	16.9	0.08	0.04
S7	**Gellibrand**	Re-veg	S7-R	9:40	n/a	99.8	10	14.7	15.17	0.13	0.06
S8	**Gellibrand**	Re-veg	S8-R	10:20	n/a	105.1	10.7	34.3	15.29	0.13	0.06
S9	**Carlisle**	Re-veg	S9-R	12:40	n/a	123.8	12.2	42.5	15.9	0.08	0.04
S10	**Carlisle**	Natural	S10-N	13:50	n/a	128.6	12.9	35	15.04	0.09	0.04
S11	**Gellibrand**	Willows	S11-W	15:20	n/a	103	9.9	27.9	17.55	0.12	0.06
S12	**Loves Creek**	Willows	S12-W	15:55	n/a	26	2.6	75	15.75	0.42	0.2
S13	**Lardners Creek**	Willows	S13-W	9:50	n/a	87.7	9.1	9.5	13.65	0.09	0.04
S14	**Gellibrand**	Willows	S14-W	10:35	n/a	85.1	8.5	40	15.37	0.13	0.06
S15	**Loves Creek**	Re-veg	S15-R	11:15	n/a	88.4	8.8	11.9	15.71	0.66	0.33
S16	**Loves Creek**	Natural	S16-N	11:58	n/a	82.6	8.2	18.7	15.6	0.46	0.23
S17	**Ten Mile Creek**	Natural	S17-N	12:30	n/a	119	13.3	20.5	12.27	0.4	0.2
S18	**Stevensons Falls**	Willows	S18-W	2:42	n/a	116.7	11.9	36	14.25	0.09	0.04

Table 1. Water quality parameters of each of the invertebrate sampling sites within the Gellibrand catchment for the Spring Collection, measured between 27 & 29 November 2007

Site	River	Habitat	Site Code	Time	pH	D.O.%	D.O. mg/L	Turb ntu	Temp.	Cond. µs	Salinity ppt
S1	**Gellibrand**	Willows	S1-W	9:40	7.71	82	8.8	0	12.21	0.22	0.14
S2	**Carlisle**	Re-veg	S2-R	10:17	6.77	87.1	9.5	0	11.18	0.17	0.08
S3	**Carlisle**	Re-veg	S3-R	10:48	7.63	108.3	11.4	23.4	11.33	0.05	0.03
S4	**Boggy Creek**	Natural	S4-N	2:30	6.76	87.4	9.4	23.4	11.92	0.17	0.08
S5	**Gellibrand**	Natural	S5-N	2:13	9.84	98	10.3	7.5	12.8	0.11	0.08
S6	**Gellibrand**	Natural	S6-N	2:38	9.75	98.2	10.3	0	12.93	0.11	0.08
S7	**Gellibrand**	Re-veg	S7-R	9:31	6.04	71.8	7.7	0	12.42	0.16	0.08
S8	**Gellibrand**	Re-veg	S8-R	9:45	6.66	74.5	8	0.5	12.4	0.16	0.08
S9	**Carlisle**	Re-veg	S9-R	12:02	7.26	88.7	9.3	13.2	12.97	0.16	0.08
S10	**Carlisle**	Natural	S10-N	1:02	8.97	106.1	11.5	19.7	11.3	0.17	0.08
S11	**Gellibrand**	Willows	S11-W	10:39	6.61	77.1	8.2	0.2	12.4	0.16	0.08
S12	**Loves Creek**	Willows	S12-W	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
S13	**Lardners Creek**	Willows	S13-W	10:02	7.01	64.5	7.2	0	10.5	0.11	0.06
S14	**Gellibrand**	Willows	S14-W	10:34	7.73	74.6	8.1	0	11.48	0.17	0.08
S15	**Loves Creek**	Re-veg	S15-R	10:56	7.98	87	9.7	0	10.52	0.8	0.4
S16	**Loves Creek**	Natural	S16-N	11:30	8.2	88	9.8	3.4	10.51	0.49	0.21
S17	**Ten Mile Creek**	Natural	S17-N	12:05	8.69	11.5	11.3	7.3	10.27	0.3	0.18
S18	**Stevensons Falls**	Willows	S18-W	13:30	9.01	80.6	8.8	0	11.23	0.11	0.05

Table 2 Water quality parameters of each of the invertebrate sampling sites within the Gellibrand catchment for the Autumn Collection, measured between 19 & 21 April 2008 (Note: Site 12 not sampled as it was dry)

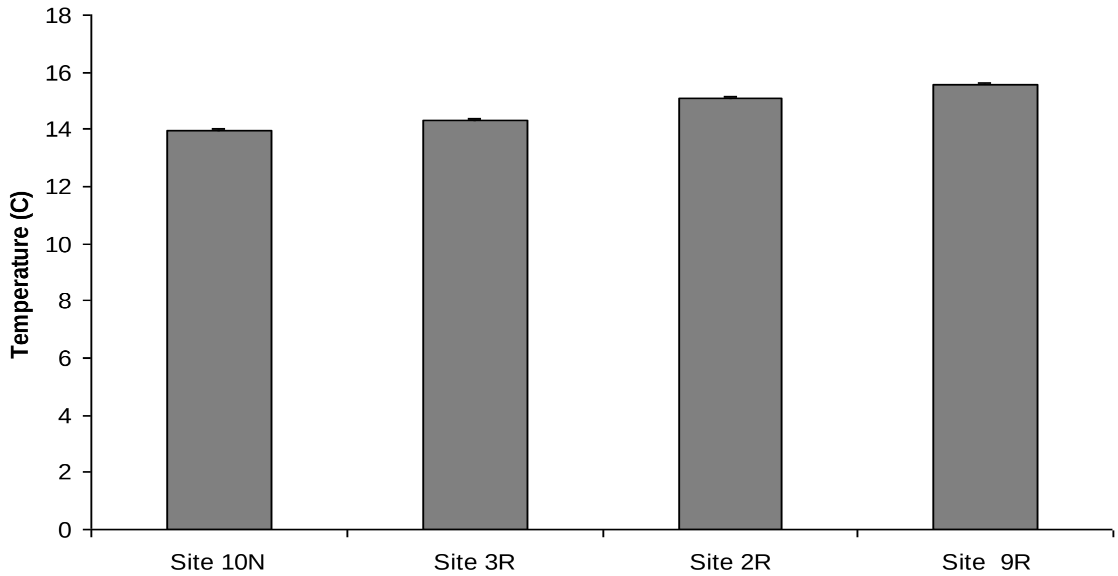

Figure 2. Mean temperature (°C) between 12:00 and 15:00, recorded by the loggers at the four sites within the Carlisle River during February to April 2008 (+ s.e.)

Water temperature increased in a downstream trend within the four sites located along the Carlisle River (Figure 2). Differences in mean temperature between the coolest and warmest site was 1.6°C. There was progressively less shade provided by riparian vegetation at each of the downstream re-vegetated sites (Site 3R-9R). Maximum recorded temperatures occurred at the two downstream re-vegetated sites (2R and 9R) where temperature exceeded 23°C at times while the lowest recorded maximums occurred in forested sites where temperatures never exceed 19.5°C.

There was large variation in mean light intensity (Lux) recordings both within sites and between sites across the catchment (Figure 3). Following transformation, a significant ($F_{7, 23} = 16.64; P < 0.01$) difference between sites was found. Site 16N recorded the lowest light intensity while site 2R had the highest, although there was a large amount of within site variability. Pairwise comparisons showed that mean light intensity at the eight year old revegetated sites was not significantly different to that at the revegetated sites, whereas the younger revegetated sites generally had much higher light exposure (Figure 3).

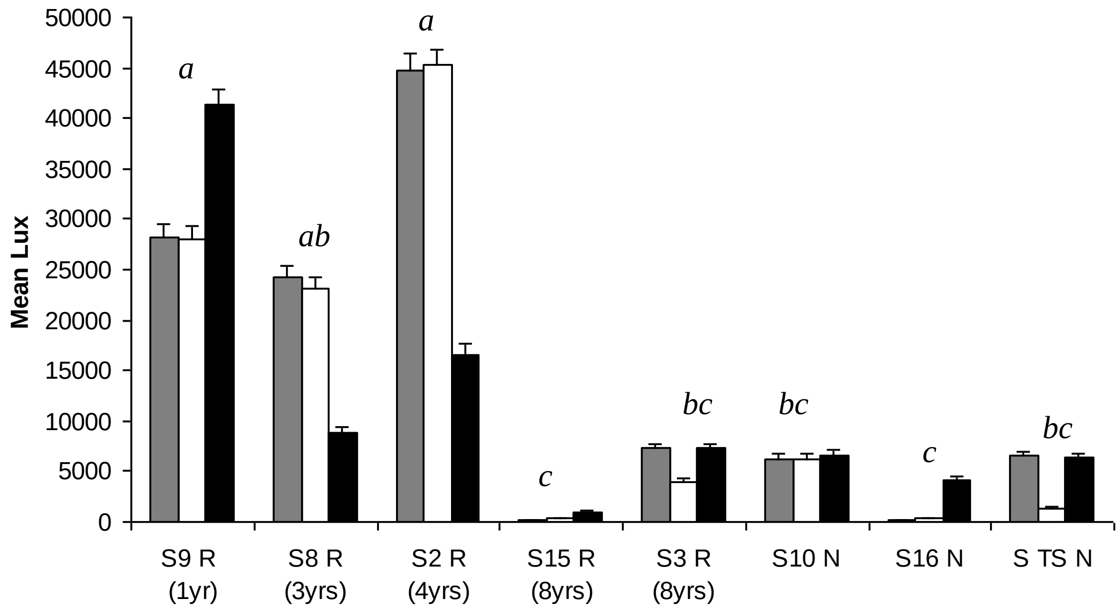

Figure 3. Mean light (Lux) between 12:00 and 15:00, recorded by the three loggers at each of the eight sites within the Gellibrand catchment during February to April 2008 (+ s.e.). Time since revegetation works were carried out is shown in parenthesis. Sites sharing the same lower-case lettering were not significantly different in mean light intensity.

Invertebrate Abundance and Diversity

A total of 34 083 individuals, comprising 119 taxa were collected during the two sampling trips across the 18 sites (Appendix 2). Blackfly larvae (Simuliidae) were the most common taxon (4662) followed by larvae of the caddisfly *Costora delora* (2955), snails (Hydrobiidae) (2488) and mayfly nymphs (*Koornonga* AV1) (2277). Total invertebrate abundance was significantly higher ($F_{1,35} = 25.4$; $P < 0.01$) during autumn within both natural, re-vegetated and willow sites (Figure 4). There was no difference in total abundance between natural, re-vegetated or willow sites and no significant interaction between site type (natural, re-vegetated, willow) and season (spring, autumn). There was no significant difference in diversity between seasons or between the three site types in either spring or autumn (Figure 5).

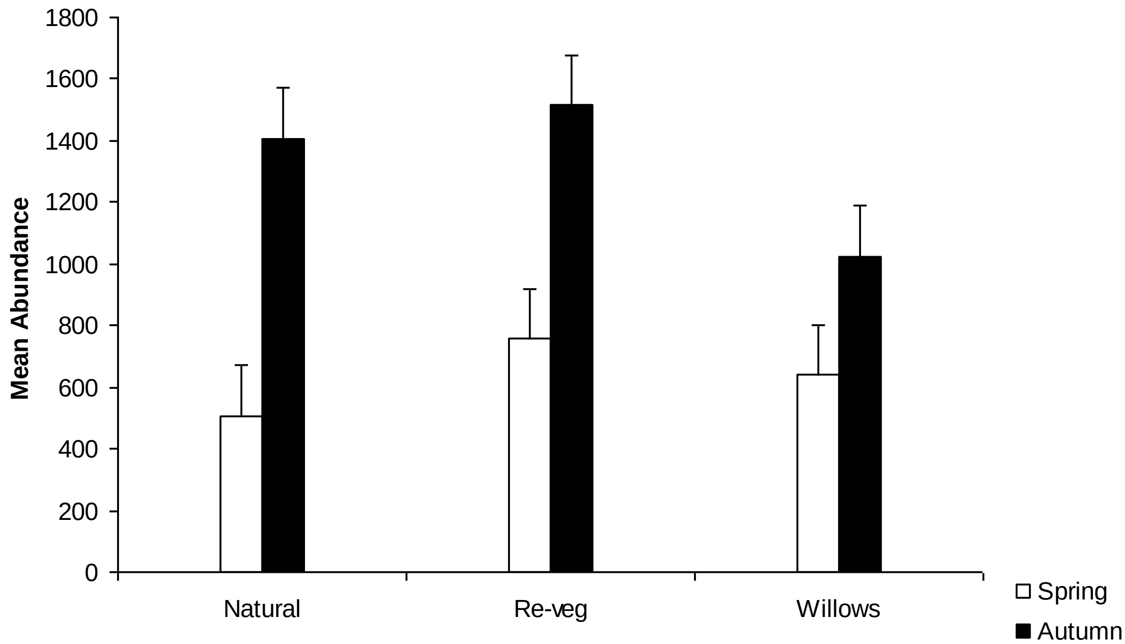

Figure 4. Number of invertebrates collected from natural, revegetated and willow sites within the Gellibrand catchment during Spring 2007 and Autumn 2008 (+ 1 s.e.)

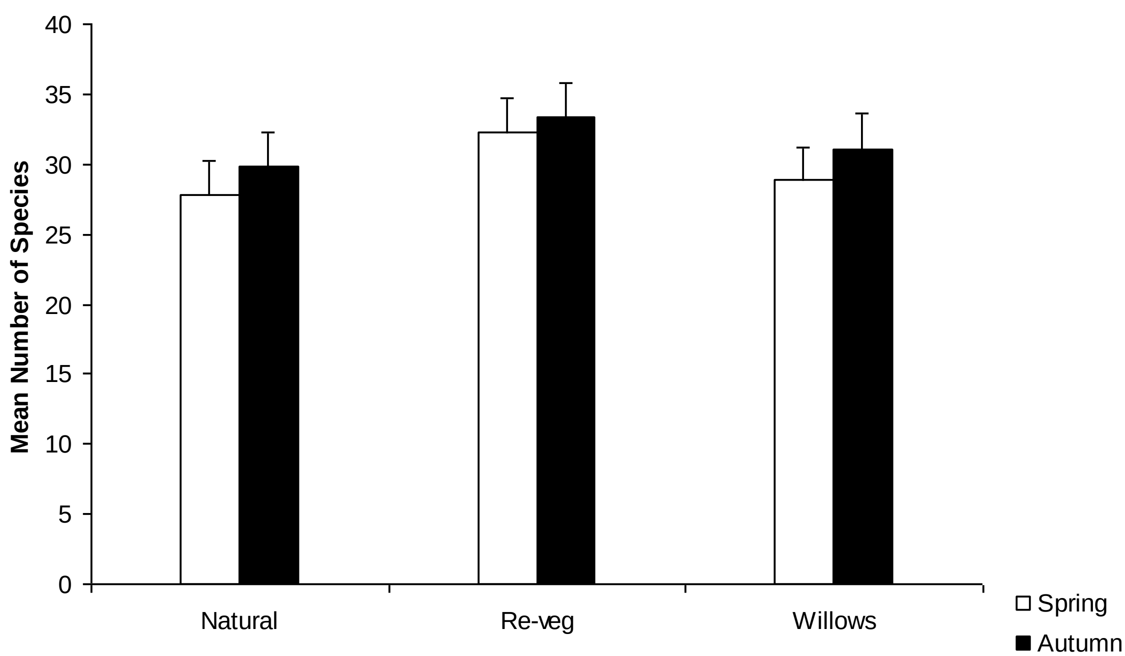

Figure 5. Number of species of invertebrates collected from natural, revegetated and willow sites within the Gellibrand catchment during Spring 2007 and Autumn 2008 (+ 1 s.e.)

Invertebrate Assemblage

One-way ANOSIM indicated there were few differences in invertebrate assemblages between natural, re-vegetated and willow sites during spring (Global R = 0.059; $P > 0.05$). However pairwise comparisons did identify significant differences between natural and re-vegetated sites (R = 0.202; $P < 0.05$) but not between willow and natural or willow and re-vegetated (Figure 6). Similarity percentage analysis found the trichoptera *Costora delora* and *Hampa partona* along with baetid mayflies were collectively responsible for 10% of the difference between the natural and re-vegetated sites, due to a higher abundance of each taxon within re-vegetated sites. A difference in variability between the three types of site was the clearest pattern in the nMDS with the re-vegetated sites forming a relatively tight group within the centre of the ordination (Figure 6). Spread around this the willows formed a slightly more divergent group while the natural sites showed a high degree of variability and were spread widely over the bottom of the ordination. This was also shown in the multivariate dispersion analysis (MVDISP) where dispersion of re-vegetated sites was found to contrast most strongly with that of native sites. The index of multivariate dispersion (IMD) which runs on a scale of -1 to 1 was found to be -1 for the pairwise comparison between these two types indicating strong differences between their variability. The one willow outlier in the top left of the ordination was site 12W, at the time of sampling this site had stagnant water and low diversity with a high abundance of dipteran larvae.

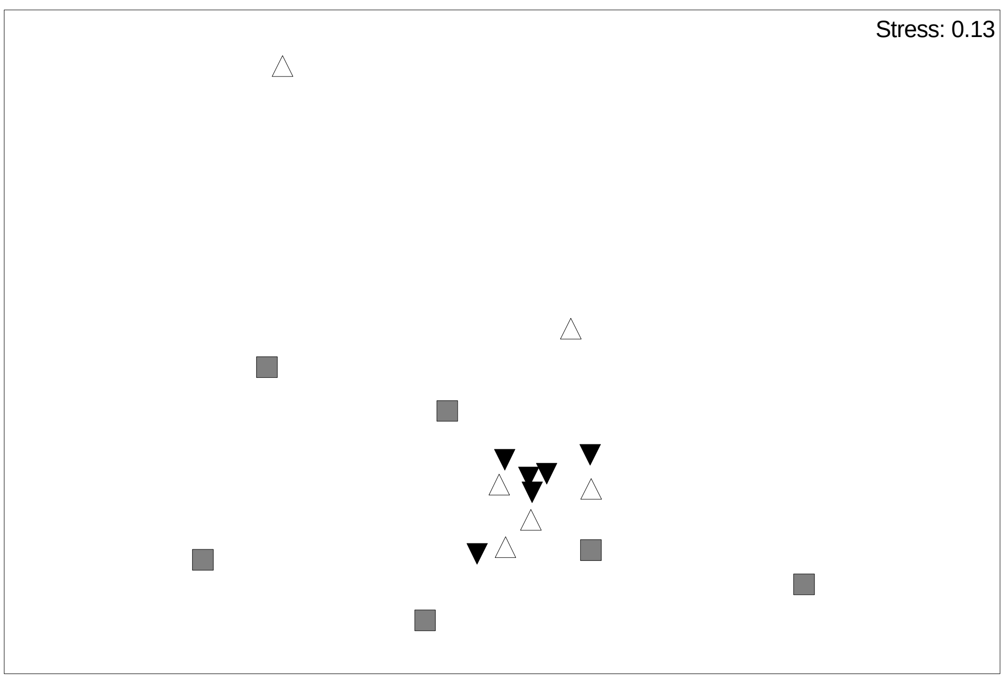

Figure 6. Non-metric multi-dimensional scaling ordination of invertebrates collected from willow (∆), re-vegetation (▼) and natural (■) sites within the Gellibrand catchment during Spring (November 27-29 2007)

During autumn, analysis of similarities identified a significant difference between the three site types (Global R = 0.174; $P < 0.05$). Pairwise comparisons revealed a significant difference between willow and re-vegetated sites (R = 0.312; $P < 0.05$) and between re-vegetated and natural sites (R = 0.141; $P = 0.05$). Similarity percentage analysis found changes in the abundance of Simuliidae, Hydrobidae, *Costora delora* and *Hampa partona* were responsible for 53% of the difference between willow and re-vegetated sites. Changes in the abundance of simuliidae, hydrobidae, *Costora delora* and tanypodinae were found to be responsible for 34% of the dissimilarity between re-vegetated and natural sites. Similar to spring, re-vegetated sites formed a relatively tight group within the centre of the nMDS ordination (Figure 7), with willow sites spread further around these. Again, natural sites were found to be the most variable with a large spread around the ordination. Multivariate dispersion analysis again identified that the greatest pairwise difference in variability lay between native and re-vegetated sites with a IMD value of -0.876 indicating strong differences in dispersion between these types of sites.

There was a significant difference in the invertebrate assemblage within the Gellibrand Catchment between spring and autumn (Global R = 0.318; $P = 0.01$). This was mostly driven by a higher abundance of many taxa during autumn, although Hydrobidae, Baetids, Tanypodinae and Simuliidae were found to be most influential, accounting for 11% of the difference. A nMDS ordination clearly shows the pattern of divergence between sites sampled during spring to those during autumn (Figure 8).

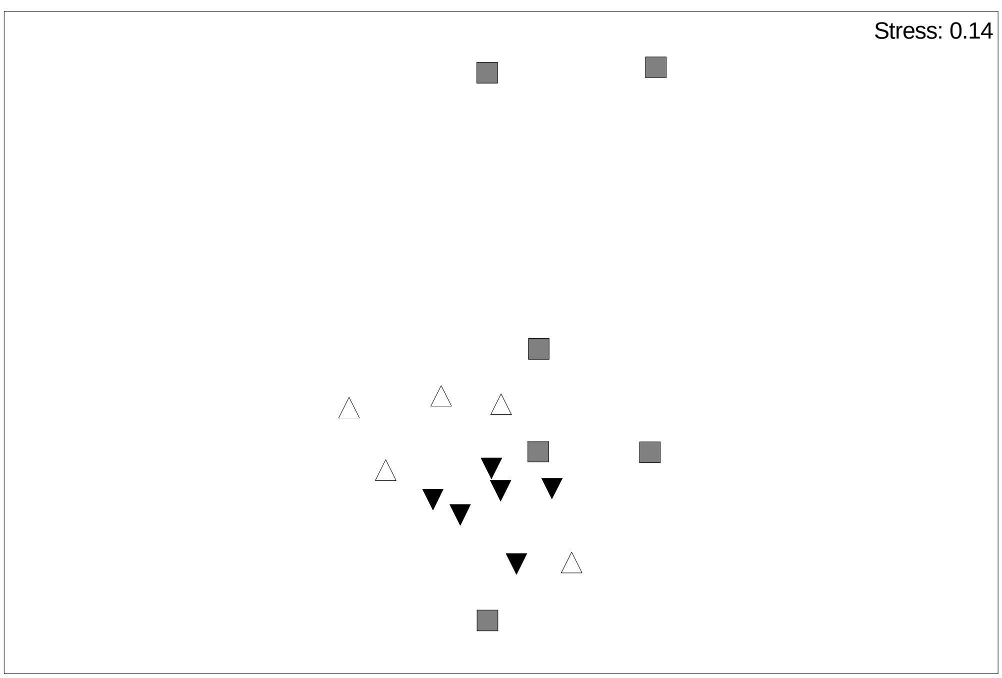

Figure 7. Non-metrical multi-dimensional scaling ordination of invertebrates collected from willow (∆), re-vegetation (▼) and natural (■) sites within the Gellibrand catchment during Autumn

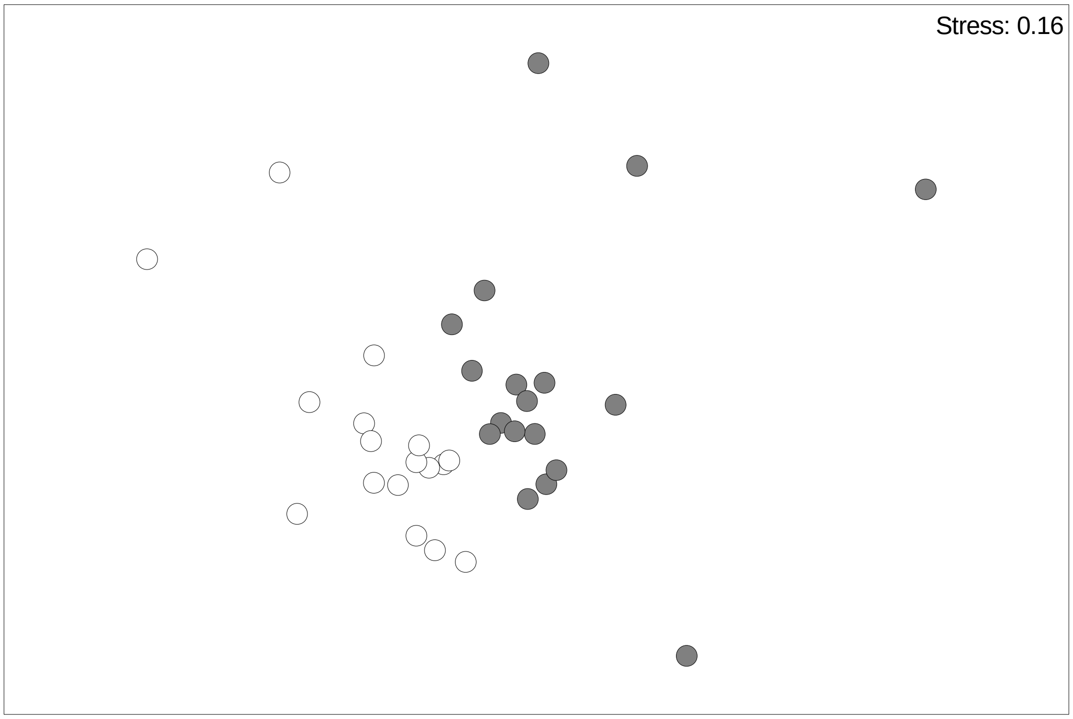

Figure 8. Non metric multi-dimensional scaling ordination of invertebrates collected during Spring 2007 (●) and Autumn 2008 (○) from sites within the Gellibrand catchment.

Summary of Fish Abundance and Diversity

Three hundred and thirty four fish, representing eight species were captured, identified and measured from the 8 locations sampled. Further, an additional 123 fish were observed but could not be captured after two passes of sampling. These fish could not be accurately identified to species level, but are included in estimates and comparisons of site total abundance. More fish (289) were collected from re-vegetated sites compared to natural forested sites (168). Despite this there was no significant difference ($P > 0.05$) in the mean number of fish collected between the two site types.

Natural sites along the Gellibrand River had both the highest number of species (six) and lowest (four) recorded within a site, the mean number of species across all sites was five species. Brown trout (*Salmo trutta*), short finned eel (*Anguilla australis*) and lamprey ammocoete (juveniles) were widely dispersed and were found at each of the eight sites sampled. River blackfish (*Gadopsis marmoratus*) were only recorded at four sites and were not located in re-vegetated sites within the Carlisle River.

Summary of Fish Assemblages

One-way analysis of similarity indicated the fish assemblage weakly differed between re-vegetated and natural sites (Global R = 0.188; *P* = 0.08, Figure 9). Four species, common galaxias (Galaxias maculatus), river blackfish (*Gadopsis marmoratus*), short headed lamprey (*Mordacia mordax*) and mountain galaxias (*Galaxias olidus*) discriminated assemblage composition contributing to 67% of difference between natural and re-vegetated sites. Higher abundances of common galaxias, short headed lamprey and lamprey ammocoetes (juvenile lampreys) occurred in the re-vegetated sites while abundances of river blackfish and mountain galaxias were more prominent in the natural sites. For more detail on the results of the fish survey see the independent report submitted by Travis Howson.

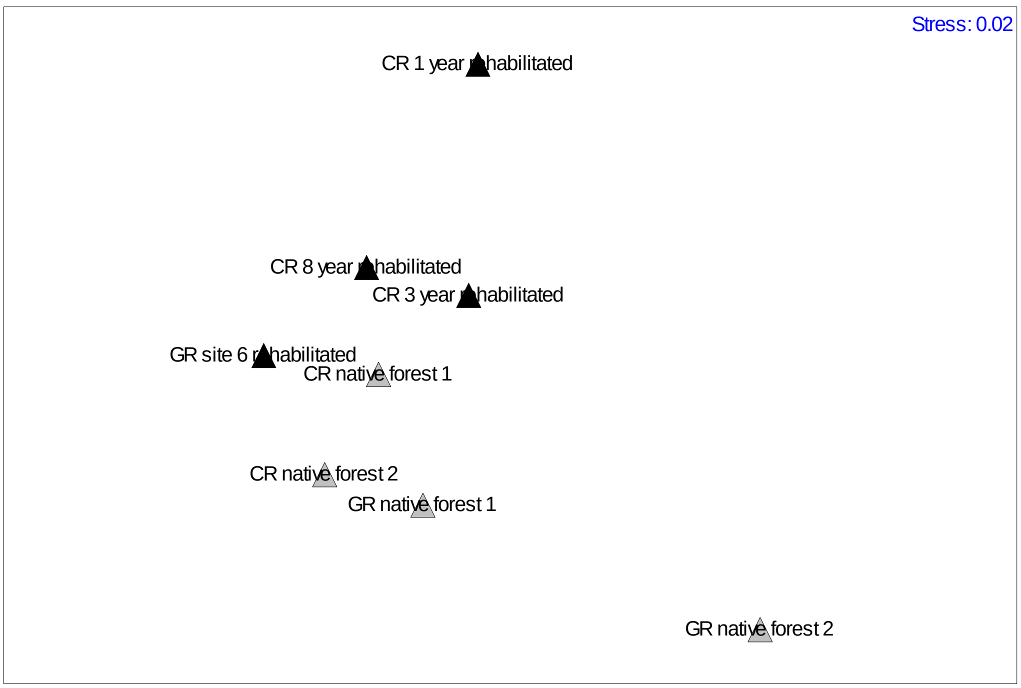

Figure 9 Non-metric multi-dimensional ordination of fish assemblages from re-vegetated (▲) and natural (▲) sites within the Gellibrand Catchment during January and February 2008

Discussion

Water temperature and Light

Water temperature can have strong ecological impacts on stream communities, with higher temperatures being particularly influential (Cox and Rutherford, 2000; Rutherford et al., 2004). Stream temperature was found to vary between sites across the catchment and there was little within site variability. Natural sites within forested sections of the catchment recorded the lowest mean temperature as well as the lowest maximum temperatures during the middle of the day with temperatures never exceeding 19.7°C. This is likely due to the large amount of shading provided by high canopy riparian vegetation. Within the Carlisle River there was a constant downstream increase in temperature at the four sites, this also correlates with re-vegetation works becoming progressively more recent. The most downstream site (9R) had willows removed only 12 months prior to the November sampling trip, while the uppermost re-vegetated site (3R) had works completed eight years ago. There was no riparian shading at site 9R (although the high banks did provide some shade) while there was extensive shading at site 3R and an intermediate amount at site 2R. Stream width at each site was similar and the three sites were adjacent to one another along a 2km stretch of stream. It appears that willow removal initially results in higher stream temperatures but as replanted native vegetation matures and provides shading, water temperature decreases and becomes more constant with lower maxima. Temperatures at the eight year old revegetated sites are now approaching those recorded at the sites with natural native vegetation.

Light intensity was highly variable both within sites and between sites although followed the same general trends as the temperature data. Light intensity was highest sites which had been re-vegetated less than fours ago (2R, 8R and 9R) and was lowest at the natural sites as well as site 15R which is a re-vegetated site on Loves Creek adjacent to Wonga Rd and site 3R. Both these sites had works completed 8 years ago. Therefore, light inputs at the eight year old revegetated sites are similar to those at native vegetation sites.

Invertebrate Community

Abundance of invertebrates was significantly higher during autumn at all types of sites. In particular, there was an increase in the numbers of Hydrobidae, Baetid mayflies and Simuliidae. Given that there were seasonal differences in total abundance at sites of each type, it may indicate that although differences in structure and temperature exist between the three site types, seasonality is still an overriding factor. There were no differences in total abundance between the three habitat types in either season. While previous studies have identified differences in invertebrate abundance between native (redgum) and willow sites, these were found to only occur during mid summer and not within spring or autumn (Read and Barmuta, 1999).

Diversity differed little between the three site types and between seasons. There were between 25 and 35 species within each of the different site types and this was consistent during both spring and autumn. There were few species which were restricted to only one type of site, with an exception being some species of trichoptera only found within natural sites and the odd rare species occurring in a single sample.

Multivariate analysis of the community assemblage revealed a consistent pattern during both spring and autumn. Re-vegetated sites appeared to show limited variation in their assemblages and formed relatively tight groups within MDS ordinations. Around these groups, the willows showed higher variability and the assemblages were found to be significantly different to re-vegetated sites during autumn. Natural sites had the highest degree of variability and were generally widely spread over the MDS ordinations and found to be significantly different to re-vegetated sites during spring and both re-vegetated and willow sites during autumn. The sites sampled for this study were spread throughout the upper regions of the Gellibrand catchment, with the willow sites having the greatest geographical spread. The large variation in invertebrate assemblages in natural sites cannot therefore be explained by geographical distance.

The willow removal process is destructive and initially leaves the stream with few habitat types (e.g. macrophytes, woody debris, riffles, pools) (Holland and Davies, 2007). These works appear to have resulted in assemblages which are relatively homogenous. Over time, as communities within re-vegetated sites continue to establish, it is likely that these assemblages will begin to become more distinct from one another and show patterns similar to those observed within the natural sites. However it appears that eight years is not a sufficient period of time for this to occur at these sites.

Fish Assemblage

Four species: common galaxias, short-headed lamprey, river blackfish and mountain galaxias strongly contributed to spatial differences in assemblage composition. Rehabilitated sites contained higher abundances of common galaxias and lampreys, but a low abundance of river blackfish and no mountain galaxias compared to forest locations. Other abundant species, including short-finned eel and brown trout, did not discriminate fish assemblage structure among site types well. Progressive, longitudinal changes in fish species composition along rivers has been widely documented , indicating the observed differences in species composition and abundances between rehabilitated and native forest locations in this study may reflect separation between native forest (riparian zones situated in hilly areas) and rehabilitation (riparian zones situated in flatter floodplain areas downstream), thus represent an underlying upstream-downstream spatial pattern.

River blackfish and mountain galaxias only occurred in some abundance at native forest sites, and were often absent from rehabilitated sites, suggesting that further examination of habitat structure is needed to assess how the populations of these species use the environment in the Gellibrand River catchment. Native forest sites were selected to contain a similar channel structure to that of rehabilitated sites in order to avoid confounding, however, the amount of woody debris appeared higher at native forest sites. Woody debris is a critical component of river ecosystems, providing support to fish including sites for foraging, spawning and refuge from natural disturbance (Crook and Robertson, 1999; Inoue and Nakano, 1998; Jackson, 1978) . Both river blackfish and mountain galaxias are known to be associated with woody debris in rivers (Koehn and O'Conner, 1990), but this study did not investigate the contribution of the riparian vegetation to site woody debris loads and fish assemblage structure. Saddlier (2005) expressed concern over the amount of large woody debris present, probably from a change in riparian structure from native vegetation to willows. It is anticipated in time, riparian revegetation as part of the rehabilitation procedure will contribute amounts of woody debris to the river environment. Therefore, it is difficult to determine why the revegetated sites had few blackfish and no mountain galaxids – this pattern may be due to differences in gradient as well as riparian type and land use history. Blackfish in particular are likely to be relatively slow colonizers of sites. If the pattern is simply due to river gradient then it may not be realistic to expect these two fish species to occur at the revegetated sites. Alternatively, more time and more woody debris may be required to assist fish migration. Lastly, it is important to note that this fish survey was a snapshot and that more comprehensive sampling may reveal additional species present at the sites at other times of year.

Conclusion

Water temperatures were higher at re-vegetated sites where works had recently been conducted and cooler in natural forests and long established re-vegetated sites. Invertebrate abundances at each site type showed similar seasonal patterns indicating seasonality has a greater bearing on abundance than stream structure or spatial variation in temperature. Assemblages within re-vegetated sites show little variation compared to natural or willow sites and this may be a response to the disturbance caused by the willow removal process. Over time, as re-vegetated works become established invertebrate assemblages may begin to show the highly variable pattern of assemblages within natural sites. Fish assemblage composition differed between rehabilitated and native forest sites, due to higher abundances of common galaxias (*Galaxias maculatus*) and adult short-headed lamprey (*Mordacia mordax*) and low abundance/absence of river blackfish (*Gadopsis marmoratus*) and mountain galaxias (*Galaxias olidus*) in rehabilitated sites. Low numbers of adult river blackfish and the absence of juvenile river blackfish in this study suggest further sampling is necessary to identify the distribution and abundance of juvenile river blackfish.

Therefore, this study shows that eight year old revegetated sites have similar light and temperature conditions to native vegetation sites. However, the fish and invertebrate fauna do not yet closely resemble those at native vegetation sites. In particular, the invertebrate assemblages are remarkably uniform at revegetated sites, regardless of site age, compared to both willow and native vegetation sites. It is worth noting though, that strong seasonal differences shown by willow and native vegetation sites are also reflected in revegetated sites, demonstrating that seasonal stream processes are occurring at all site types. The revegetated sites within the Gellibrand catchment are therefore becoming more like native vegetation sites in terms of light and temperature conditions and also contain the same, common fish and invertebrate species. However, the revegetated sites have not yet been extensively colonised by two native fish species and they do not display the site-to-site variation seen in undisturbed sites and especially in sites with remnant native vegetation.

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APPENDIX 1

Site Locations

Site	River	Habitat	Site Code	Co-ordinate
S1	**Gellibrand**	Willows	S1-W	143 23' 43", 38 31' 08"
S2	**Carlisle**	Re-veg	S2-R	143 24' 04", 38 33' 52"
S3	**Carlisle**	Re-veg	S3-R	143 24' 11", 38 34' 19"
S4	**Boggy Creek**	Natural	S4-N	143 24' 05", 38 33' 56"
S5	**Gellibrand**	Natural	S5-N	143 36' 16", 38 32' 29"
S6	**Gellibrand**	Natural	S6-N	143 36' 27", 38 32' 55"
S7	**Gellibrand**	Re-veg	S7-R	143 32' 25", 38 31' 14"
S8	**Gellibrand**	Re-veg	S8-R	143 32' 27", 38 31' 17"
S9	**Carlisle**	Re-veg	S9-R	143 23' 39", 38 33' 28"
S10	**Carlisle**	Natural	S10-N	143 24' 18", 38 35' 18"
S11	**Gellibrand**	Willows	S11-W	143 32' 13", 38 31' 03"
S12	**Loves Creek**	Willows	S12-W	143 32' 12", 38 30' 52"
S13	**Lardners Creek**	Willows	S13-W	143 32' 42', 38 32' 24"
S14	**Gellibrand**	Willows	S14-W	143 32' 40", 38 31' 24"
S15	**Loves Creek**	Re-veg	S15-R	143 32' 58", 38 30' 20'
S16	**Loves Creek**	Natural	S16-N	143 34' 53", 38 28' 49"
S17	**Ten Mile Creek**	Natural	S17-N	143 35' 52", 38 27' 45"
S18	**Stevensons Falls**	Willows	S18-W	143 39' 21", 38 33' 55"

Appendix 2 Macroinvertebrate species list

Family	Genus	Species
Oligochaete		Oligochaete
Ancylidae	*Ferrissia*	*Ferrissia tasmanca*
Hydrobiidae		Hydrobidae
Planorbidae		Planorbidae
Physidae	*Physa*	*Physa acuta*
Sphaeriidae	*Pisidium*	*Pisidium sp.*
Archania		Archania
Lycosidae		*Lycosidae sp.*
Tetragnathidae	*Tetragnatha*	*Tetragnatha sp.*
Amphipoda		Amphipoda
Atyidae	*Paratya*	*Paratya australiensis*
Euastacus	*Euastacus*	*Euastacus sp. 1*
Lepidoptera		Lepidoptera
Dytiscidae		*Dytiscidae sp.*
Dytiscidae Larv.		*Hyderodes sp.*
Elmidae		Elmidae sp # 1
		Elmidae sp # 2
		Elmidae sp # 3
		Elmidae sp # 4
		Elmidae sp # 5
		Elmidae sp # 6
Elmidae (Larv.)	*Austrolimnius*	*Austrolimnius sp.*
	Kingolus	*Kingolus sp.*
	Notriolus	*Notriolus sp.*
	Simsonia	*Simsonia sp.*
		Elmidae Early Instar Larv.
Halipilidae	*Haliplus*	*Haliplus sp.*
Psephenidae	*Sclerocyphon*	*Scledocyphon sp.*
Scirtidae		*Scirtidae sp.*
Ceratopogonidae		Ceratopogonidae
Chironominae		Chironominae
Orthacladiinae		Orthocladiinae
Tanypodinae		Tanypodinae
Culicidae		Culicidae
Dixidae		Dixidae
Empididae		Empididae
Sciomyzidae		Sciomyzidae
Simuliidae		Simuliidae
Tipulidae		Tipulidae
Adult Black Fly		Adult black fly
Baetidae	*Centroptilum*	*Centroptilum sp.*
	Genus 1	Genus 1 MV5
	Genus 2	Genus 2 MV3
	Unknown	Unknown Baetidae
Caenidae	*Tasmanocoenis*	*Tasmanocoenis sp 1.*
	Tasmanocoenis	*Tasmanocoenis tonnoiri*
Coloburiscidae	*Coloburiscoides*	*Coloburiscoides sp.*
Leptophlebiidae	*Atalophlebia*	*Atalophlebia albiterminata*
	Atalophlebia	*Atalophlebia* AV18

Family	Genus	Species
Leptophlebiidae	*Atalophlebia*	*Atalophlebia* AV8
	Garinjuga	*Garinjuga* AV1
	Koornonga	*Koornonga* AV1
	Neboissophlebia	*Neboissophlebia hamulata*
	Nousia	*Nousia* AV15
	Ulmerophlebia	*Ulmerophlebia* AV1
	Ulmerophlebia	*Ulmerophlebia* AV2
	Unknown	Unknown Leptophlebiidae
Oniscigastridae	*Tasmanophlebia*	*Tasmanophlebia sp.*
Corixidae	*Micronecta*	*Micronecta sp.*
	Sigara	*Sigara sp.*
		Corixidae sp # 3
Gerridae		*Gerridae sp.*
Mesoveliidae		*Mesoveliidae sp.*
Notonectidae		*Notonectidae sp.*
Veliidae		Veliidae sp # 1
		Veliidae sp # 2
Synthemistidae	*Choristhemis*	*Choristhemis flavoterminata*
Synlestidae	*Synlestes*	*Synlestes weyersii*
Telephlebiidae	*Austrophlebia*	*Austrophlebia costalis*
	Antipodophlebia	*Antipodophlebia asthenes*
		Epiproctophora early instar
Austroperlidae	*Acruroperla*	*Acruroperla atra*
Gripopterygidae	*Dinotoperla*	*Dinotoperla christinae*
		Dinotoperla sp.
	Illiesoperla	*Illiesoperla australis*
	Leptoperla	*Leptoperla tasmanica*
		Leptoperla kimminsi
		Leptoperla primitiva
		Leptoperla albicincta
		Leptoperla truncata
	Newmanoperla	*Newmanoperla thoreyi*
		Gripopterygidae early instar
	Riekoperla	*Riekoperla tuberculata*
Atriplectididae	*Atriplectides*	*Atriplectides dubius*
Calamoceratidae	*Anisocentropus*	*Anisocentropus sp.*
Calocidae	*Tamasia*	*Tamasia variegata*
Conosucidae	*Costora*	*Costora delora*
	Hampa	*Hampa patona*
	Conoesucus	*Conoesucus* AV1
Economidae		*Economidae sp.*
Hydrobiosidae	*Taschorema*	*Taschorema evansi*
	Apsilochorema	*Apsilochorema obliquum*
	Ethochorema	*Ethochorema sp.1*
		Ethochorema nesydrion
	Psyllobetina	*Psyllobetina locula*
	Koetonga	*Koetonga clivicola*
	Ulmerochorema	*Ulmerochorema lentum*

Family	Genus	Species
Hydropsychidae	*Diplectrona*	*Diplectrona sp.*
	Smicrophylax	*Smicrophylax* AV2
	Smicrophylax	*Smicrophylax parvula*
Helicopsychidae	*Helicopsyche*	*Helicopsyche heacota*
	Alloecella	*Alloecella grisea*
Leptoceridae	*Notalina*	*Notalina* AV25
		Notalina fulva
		Notalina bifaria
		Notalina spira
	Condocerus	*Condocerus paludosus*
	Lectrides	*Lectrides varians*
	Oecetis	*Oecetis sp.*
	Triplectides	*Triplectides similis*
		Triplectides varius
		Triplectides truncatus
		Triplectides ciuskus cuiskus
		Triplectides australicus
		Triplectides proximus
Philorheithridae	*Austrheithrus*	*Austrheithrus sp.*
	Kosrheithrus	*Kosrheithrus sp.*